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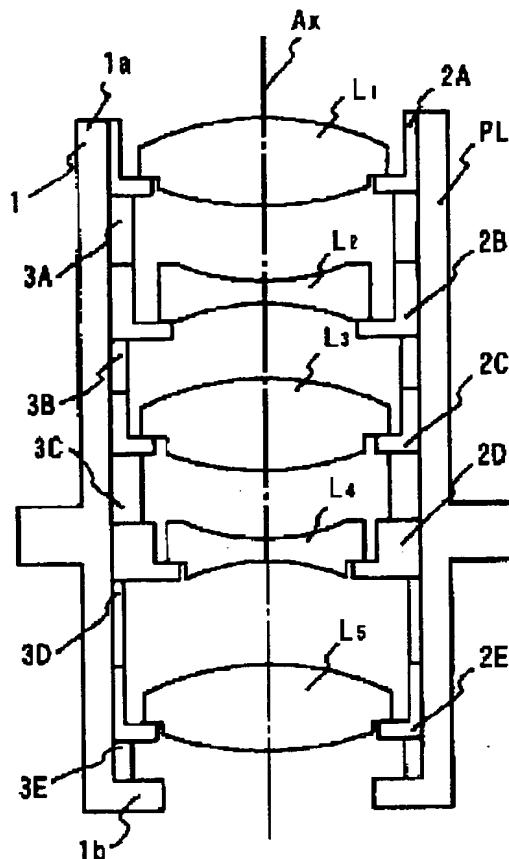
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TITLE : MANUFACTURE OF PROJECTION OPTICAL SYSTEM, PROJECTION ALIGNER, AND SEMICONDUCTOR DEVICE



ABSTRACT : PROBLEM TO BE SOLVED: To eliminate an aberration component of higher-order from a projection optical system without incurring the malfunction of optical parts and the projection optical system itself by a method wherein an spherical surface which corrects the optical system for higher-order aberration left in it is provided to the optical member basing on the surface shape of the optical member, a space between the optical surfaces of the optical member, and the optical design data of the projection optical system.

SOLUTION: A plurality of optical members L₁ to L₅ are arranged in a prescribed order and assembled into a projection optical system PL. The projection optical system PL is corrected for aberration of higher-order by turning the optical surface (refracting surface of the like) of an optical member inside the projection optical system PL spherical (fine spherical surface) after one out of the plurality of optical members L₁ to L₅ comprising the projection optical system PL is moved (the optical members L₁ to L₅ are changed in space between them, moved in the direction of an optical axis or in the direction vertical to an optical axis, an tilted) to adjust the assembled projection optical system PL or the optical members L₁ to L₅ are assembled into a projection optical system PL.

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CLAIMS

[Claim(s)]

[Claim 1] In the manufacture approach of the projection optics for projecting the image of the 1st body to up to the 2nd body The 1st process which manufactures two or more optical members which should constitute said projection optics, The 2nd process which measures the field configuration of the optical surface of two or more optical members manufactured according to this 1st process, respectively, The 3rd process which assembles projection optics using said two or more optical members manufactured at said 1st process, In order to amend the aberration measured by the 4th process and this 4th process for measuring the aberration which remains in said projection optics after this 3rd process, while adjusting said projection optics The 5th process which asks for spacing of the optical surface between said two or more optical members which constitute said projection optics in the time during this adjustment of the completion of adjustment, The 6th process which measures the high order aberration which remains in said projection optics after said 5th process, The information on the field configuration of each optical member obtained at said 2nd process, and the information on spacing of the optical surface between said two or more optical members obtained at said 5th process, The manufacture approach of the projection optics characterized by having the 7th process which forms the aspheric surface which amends the amount of high order aberration which was obtained at said 6th process, and which remains in at least one of said two or more of the optical members based on the optical design information on said projection optics.

[Claim 2] Said aspheric surface formed at said 7th process is the manufacture approach of the projection optics according to claim 1 characterized by satisfying $0.02 < S(n-1) / \lambda < 0.483$ when setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which λ and said aspheric surface are formed in exposure wavelength.

[Claim 3] The manufacture approach of the projection optics according to claim 1 or 2 characterized by satisfying $|C| < 0.02$ when forming said aspheric surface in the refracting interface of said optical member and setting the curvature of this refracting interface to C.

[Claim 4] The die length of said projection optics which met the optical axis to the refracting interface of the optical member by the side of the 2nd body most is most set to D from the refracting interface of the optical member by the side of the 1st body. said projection optics -- The manufacture approach of projection optics given in either of claim 1 to claims 3 characterized by satisfying the conditions of $0 < d/D < 0.37$ when setting to d distance in alignment with the optical axis to the refracting interface of the optical member in which said aspheric surface is most formed from the refracting interface of the optical member by the side of the 1st body of said projection optics.

[Claim 5] The distance which said aspheric surface set the height from an optical axis to h, and met the optical axis from the point on the aspheric surface in height h from an optical axis to the tangential plane in lens top-most vertices X (h), the radius of curvature of paraxial -- r and a cone constant -- the natural numbers from k and at least 1 to 12 -- n and the n-th aspheric surface multiplier -- C_n -- the manufacture approach of projection optics given in either of claim 1 to claims 4 by which it is

characterized [it is satisfied with of the following formulas] when carrying out.

$X(h) = A/[1+(1-kA/r) 0.5]+C1 h1+C2 h2+C3 h3+C4 h4+ \dots$ They are $+Cn hn$, however $A=h2 / r$.

[Claim 6] In the projection aligner which illuminates the exposure light from an illumination-light study system to the pattern formed on the mask, and exposes this pattern to a photosensitive substrate through projection optics said projection optics It has two or more optical members for forming the image of said pattern in said photosensitive substrate. The aspheric surface for amending the aberration component which remains in said projection optics is formed in at least one of said two or more of the optical members. The projection aligner characterized by satisfying $0.02 < S(n-1) / \lambda < 0.483$ when setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which λ and said aspheric surface are formed in exposure wavelength.

[Claim 7] The projection aligner according to claim 6 characterized by satisfying $|C| < 0.02$ when forming said aspheric surface in the refracting interface of said optical member and setting the curvature of this refracting interface to C.

[Claim 8] The die length of said projection optics which met the optical axis to the refracting interface of the optical member by the side of a photosensitive substrate most is most set to D from the refracting interface of the optical member by the side of a mask. said projection optics -- The projection aligner according to claim 6 or 7 characterized by satisfying the conditions of $0 \leq d/D < 0.37$ when setting to d distance in alignment with the optical axis to the refracting interface of the optical member in which said aspheric surface is most formed from the refracting interface of the optical member by the side of a mask of said projection optics.

[Claim 9] The distance which said aspheric surface set the height from an optical axis to h, and met the optical axis from the point on the aspheric surface in height h from an optical axis to the tangential plane in lens top-most vertices X (h), the radius of curvature of paraxial -- r and a cone constant -- the natural numbers from k and at least 1 to 12 -- n and the n-th aspheric surface multiplier -- $Cn **$ -- projection aligner given in either of claim 6 to claims 8 by which it is characterized [it is satisfied with of the following formulas] when carrying out.

$X(h) = A/[1+(1-kA/r) 0.5]+C1 h1+C2 h2+C3 h3+C4 h4+ \dots$ They are $+Cn hn$, however $A=h2 / r$.

[Claim 10] The process which illuminates exposure light in the approach of manufacturing a semiconductor device, to the predetermined pattern formed on the mask, It has the process which carries out projection exposure of said pattern through projection optics at a photosensitive substrate. Said projection optics It has two or more optical members for forming the image of said pattern in said photosensitive substrate. The aspheric surface for amending the aberration component which remains in said projection optics is formed in at least one of said two or more of the optical members. The manufacture approach of the semiconductor device characterized by satisfying $0.02 < S(n-1) / \lambda < 0.483$ when setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which λ and said aspheric surface are formed in exposure wavelength.

[Claim 11] An approach to manufacture the semiconductor device according to claim 10 characterized by satisfying $|C| < 0.02$, when forming said aspheric surface in the refracting interface of said optical member and setting the curvature of this refracting interface to C.

[Claim 12] The die length of said projection optics which met the optical axis to the refracting interface of the optical member by the side of a photosensitive substrate most is most set to D from the refracting interface of the optical member by the side of a mask. said projection optics -- The manufacture approach of the semiconductor device according to claim 10 or 11 characterized by satisfying the conditions of $0 \leq d/D < 0.37$ when setting to d distance in alignment with the optical axis to the refracting interface of the optical member in which said aspheric surface is most formed from the refracting interface of the optical member by the side of a mask of said projection optics.

[Claim 13] The distance which said aspheric surface set the height from an optical axis to h, and met the optical axis from the point on the aspheric surface in height h from an optical axis to the tangential plane in lens top-most vertices X (h), the radius of curvature of paraxial -- r and a cone constant -- the

natural numbers from k and at least 1 to 12 -- n and the n-th aspheric surface multiplier -- C_n ** -- the manufacture approach of a semiconductor device given in either of claim 10 to claims 12 by which it is characterized [it is satisfied with of the following formulas] when carrying out.

$X(h) = A/[1+(1-kA/r) 0.5] + C_1 h_1 + C_2 h_2 + C_3 h_3 + C_4 h_4 + \dots$ They are $+C_n h_n$, however $A=h^2 / r$.

[Claim 14] In the approach of manufacturing the projection optics for projecting the image of the 1st body to up to the 2nd body by assembling in predetermined sequence using two or more optical members The 1st process which precedes assembling said projection optics using two or more optical members, and measures the configuration of the optical surface of two or more optical members, The 2nd process which assembles projection optics using said two or more optical members, and acquires the information about arrangement of two or more of said optical members inside or after an assembly, The information about the configuration of the optical surface of two or more of said optical members obtained at said 1st process, The manufacture approach of the projection optics characterized by having the 3rd process which forms in at least one of said two or more of the optical members the aspheric surface which removes the aberration which remains in said projection optics based on the process which acquires the information about arrangement of two or more of said optical members obtained at said 2nd process.

[Claim 15] Said aspheric surface formed at said 3rd process is the manufacture approach of the projection optics according to claim 14 characterized by satisfying $0.02 < S(n-1) / \lambda < 0.483$ when setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which λ and said aspheric surface are formed in exposure wavelength.

[Claim 16] The manufacture approach of the projection optics according to claim 14 or 15 characterized by satisfying $|C| < 0.02$ when forming said aspheric surface in the refracting interface of said optical member and setting the curvature of this refracting interface to C .

[Claim 17] The die length of said projection optics which met the optical axis to the refracting interface of the optical member by the side of the 2nd body most is most set to D from the refracting interface of the optical member by the side of the 1st body. said projection optics -- When setting to d distance in alignment with the optical axis to the refracting interface of the optical member in which said aspheric surface is most formed from the refracting interface of the optical member by the side of the 1st body of said projection optics, The manufacture approach of projection optics given in either of claim 14 to claims 16 characterized by satisfying the conditions of $0 \leq d/D \leq 0.37$.

[Claim 18] The distance which said aspheric surface set the height from an optical axis to h , and met the optical axis from the point on the aspheric surface in height h from an optical axis to the tangential plane in lens top-most vertices $X(h)$, the radius of curvature of paraxial -- r and a cone constant -- the natural numbers from k and at least 1 to 12 -- n and the n-th aspheric surface multiplier -- C_n ** -- the manufacture approach of projection optics given in either of claim 14 to claims 17 by which it is characterized [it is satisfied with of the following formulas] when carrying out.

$X(h) = A/[1+(1-kA/r) 0.5] + C_1 h_1 + C_2 h_2 + C_3 h_3 + C_4 h_4 + \dots$ They are $+C_n h_n$, however $A=h^2 / r$.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]**[0001]**

[Field of the Invention] This invention is suitable for the projection aligner used about manufacture of the projection aligner which carries out projection exposure of the mask with which the predetermined pattern was formed on a photosensitive substrate, and the projection optics of that etc. at the photolithography process for manufacturing a semiconductor device, a liquid crystal display component, or the thin film magnetic heads, such as LSI, etc. especially.

[0002]

[Description of the Prior Art] What carries out projection exposure of the mask as the projection original edition with which the predetermined pattern was formed as an aligner used in order to manufacture a semiconductor device, a liquid crystal display component, or the thin film magnetic head on a photosensitive substrate through projection optics is known. The projection optics of the refraction mold which consists of lenses, such as an optical element of the refractility which has a penetrable optical property to the light of exposure wavelength as such projection optics, the projection optics of the reflective refraction mold which combined the lens as an optical element of refractility and the mirror as a reflexive optical element, and the projection optics of the reflective mold which consists of mirrors as a reflexive optical element altogether further are known.

[0003] As a projection scale factor at the time of projecting a mask pattern on a photosensitive substrate using each above projection optics, there is contraction, actual size, or a thing to expand according to the component to manufacture.

[0004]

[Problem(s) to be Solved by the Invention] generally the projection optics of the aligner used in case various kinds of above components are manufactured is close to non-aberration at high resolution, in order to project a detailed mask pattern on a photosensitive substrate -- a condition -- very high optical-character ability is required. Therefore, in order to realize projection optics with which the specification demanded in recent years is filled, the technique for manufacturing projection optics becomes one big factor. For this reason, the manufacture error of an optical member own [, such as a lens which constitutes projection optics,], Or by changing the thickness of the washer inside the lens-barrel which holds optical members, such as a lens, for the error by the assembly manufacture error produced in the phase incorporating two or more optical members etc., in case projection optics is manufactured Spacing of each optical member can be adjusted and the aberration of a low degree which occurs or remains at the time of manufacture can be amended.

[0005] However, it was impossible to have amended the high order aberration which occurs or remains at the time of manufacture by the adjustment technique of the above conventional projection optics. That is, it was difficult to remove the minute manufacture error which remains in the optical member itself, such as a lens, the minute aberration components (for example, high order image surface gryposis, high order distortion, etc.) which remain even if it adjusts spacing of an optical member.

[0006] Therefore, even if it is able to design the projection optics which the situation where an

optical element and the projection optics which carried out rigging become poor arises frequently, and has high optical-character ability, it is very difficult to manufacture projection optics. For this reason, projection exposure of the mask pattern which becomes increasingly detailed is carried out on a photosensitive substrate according to projection optics, and it becomes difficult to manufacture various kinds of components, such as a semiconductor device with a higher degree of integration.

[0007] Therefore, this invention is made in view of the above technical problem, and it can enable manufacture of projection optics with the high optical-character ability from which the high order aberration component was removed, without inviting the defect of the optic which constitutes projection optics, and the own defect of projection optics. For this reason, it aims at offering the manufacture approach of various kinds of components including the manufacture approach of the projection optics which a high order aberration component can remove, the projection aligner which can carry out projection exposure of the mask pattern good to a photosensitive substrate, and a semiconductor device with a further more high degree of integration in this invention.

[0008]

[Means for Solving the Problem] In the manufacture approach of the projection optics for carrying out projection exposure of the predetermined pattern formed on the mask at a photosensitive substrate according to the 1st mode of this invention, in order to realize the above purpose The 1st process which manufactures two or more optical members which should constitute said projection optics, The 2nd process which measures the field configuration of the optical surface of two or more optical members manufactured according to this 1st process, respectively, The 3rd process which assembles projection optics using said two or more optical members manufactured at said 1st process, In order to amend the aberration measured by the 4th process and this 4th process for measuring the aberration which remains in said projection optics after this 3rd process, while adjusting said projection optics The 5th process which asks for spacing of the optical surface between said two or more optical members which constitute said projection optics in the time during this adjustment of the completion of adjustment, The 6th process which measures the high order aberration which remains in said projection optics after said 5th process, The information on the field configuration of each optical member obtained at said 2nd process, and the information on spacing of the optical surface between said two or more optical members obtained at said 5th process, it comes out of having the 7th process which forms the aspheric surface which amends the amount of high order aberration which was obtained at said 6th process, and which remains in at least one of said two or more of the optical members based on the optical design information on said projection optics.

[0009] When setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which lambda and said aspheric surface are formed in exposure wavelength, as for said aspheric surface formed at said 7th process at this time, it is desirable to satisfy $0.02 < S(n-1) / \lambda < 0.483$.

[0010] Moreover, according to the 2nd mode of this invention, illuminate exposure light to the pattern formed on the mask, and it sets to the projection aligner which exposes this pattern to a photosensitive substrate through projection optics. Said projection optics has two or more optical members for forming the image of said pattern in said photosensitive substrate. The aspheric surface for amending the aberration component which remains in said projection optics is formed in at least one of said two or more of the optical members. When setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which lambda and said aspheric surface are formed in exposure wavelength, $0.02 < S(n-1) / \lambda < 0.483$ is satisfied.

[0011] Moreover, according to the 3rd mode of this invention, it sets to an approach to manufacture a semiconductor device. It has the process which illuminates exposure light to the predetermined pattern formed on the mask, and the process which carries out projection exposure of said pattern through projection optics at a photosensitive substrate. Said projection

optics It has two or more optical members for forming the image of said pattern in said photosensitive substrate. The aspheric surface for amending the aberration component which remains in said projection optics is formed in at least one of said two or more of the optical members. When setting the maximum variation of said aspheric surface in the direction of an optical axis of said projection optics to S and setting to n the refractive index of said optical member in which lambda and said aspheric surface are formed in exposure wavelength, it is satisfying $0.02 < S(n-1) / \lambda < 0.483$.

[0012] According to the 4th mode of this invention, moreover, by assembling in predetermined sequence using two or more optical members In the approach of manufacturing the projection optics for projecting the image of the 1st body to up to the 2nd body The 1st process which precedes assembling said projection optics using two or more optical members, and measures the configuration of the optical surface of two or more optical members, The 2nd process which assembles projection optics using said two or more optical members, and acquires the information about arrangement of two or more of said optical members inside or after an assembly, The information about the configuration of the optical surface of two or more of said optical members obtained at said 1st process, Based on the process which acquires the information about arrangement of two or more of said optical members obtained at said 2nd process, it has the 3rd process which forms in at least one of said two or more of the optical members the aspheric surface which removes the aberration which remains in said projection optics.

[0013] And it is $|C| < 0.02$, when the 1st [more than] – the 4th mode form said aspheric surface in the refracting interface of said optical member and set the curvature of this refracting interface to C. (1-/mm)

It is desirable that it is satisfied. The die length of said projection optics which met the optical axis to the refracting interface of the optical member by the side of the 2nd body (photosensitive substrate side) most is most set to D from the refracting interface of the optical member by the side of the 1st body (mask side). moreover -- the 1st [more than] – the 4th mode -- said projection optics -- When setting to d distance in alignment with the optical axis to the refracting interface of the optical member in which said aspheric surface is most formed from the refracting interface of the optical member by the side of the 1st body (mask side) of said projection optics, it is good also as a configuration with which are satisfied of the conditions of $0 < d/D < 0.37$.

[0014]

[Embodiment of the Invention] Two or more optical members are arranged in predetermined sequence, projection optics is assembled, and at least one location of two or more optical members which constitute projection optics is moved (change [spacing / between optical members]). An optical member is made migration and a pan in inclination etc. in the direction which intersects an optical member perpendicularly with the direction of an optical axis, or an optical axis. After completion of assembly adjustment, Projection optics is assembled using two or more optical members, and it sets after completion (for example, assembling projection optics including adjustment of projection optics after completion of a process etc.). Or in this invention The aberration component of the high order number which remains in projection optics is amended by changing the optical surfaces (refracting interface etc.) of a certain optical member within projection optics the aspheric surface (minute aspheric surface). When the aspheric surface (minute aspheric surface) said here assembles and manufactures projection optics using two or more optical members unlike the aspheric surface introduced in order to amend aberration positively [in order to realize projection optics with the specification of a certain request] at the time of a design, for example, assembly adjustment is carried out, the alignment error of projection optics etc. amends the high order aberration with difficult removal which remains in the manufacture error list of the optic itself.

[0015] The aspheric surface at this time adjusts projection optics after ***** using two or more optical members. Or the 1st information which it preceded assembling projection optics using two or more optical members (for example, assembling projection optics including

adjustment of projection optics process etc.), measured the configuration of the optical surface of two or more optical members, and was acquired, It is determined based on the 2nd information about arrangement of two or more optical members which assembled projection optics using two or more optical members, and were obtained in inside or an assembly completion phase. In this case, the residual aberration of the projection optics in the phase which the assembly of the projection optics using two or more optical members completed is measured, and, as for that measured amount of aberration, it is desirable to consider as the desired value at the time of determining the configuration of the aspheric surface, a location, and a number using the 1st and 2nd information of the above.

[0016] When setting the maximum variation of said aspheric surface in the direction of an optical axis of projection optics to S as the aspheric surface by this invention here and setting to n the refractive index of said optical member in which said aspheric surface is formed, it is desirable to satisfy the following (1) types.

(1) If the minimum of the $S(n-1) / \lambda < 0.483 \cdot 0.02$ above-mentioned (1) type is exceeded, since the effectiveness as the aspheric surface fades, it is not desirable. If the upper limit of the above-mentioned (1) formula is exceeded, since the refractive power of the aspheric surface will become large too much, it becomes difficult to control the aberration of a high order number. And since it becomes difficult to take out the precision on polish of the aspheric surface which should be processed in this case demanded, aspheric surface processing becomes impossible.

[0017] Moreover, when forming the aspheric surface by this invention in one [at least] refracting interfaces (a lens side, refractility flat surface, etc.) of a certain optical member (lens) which constitutes projection optics and setting the curvature in the paraxial of the refracting interface to C, it is desirable to satisfy the following (2) types.

(2) $|C| < 0.02$ (1/mm)

If the upper limit of the above-mentioned (2) formula is exceeded, since the refractive power in the refracting interface in which the aspheric surface should be formed will become large, it becomes difficult to take out the precision on polish of the aspheric surface demanded, and aspheric surface processing becomes difficult.

[0018] Moreover, when setting to D most the die length of projection optics which met the optical axis to the refracting interface of the optical member by the side of a photosensitive substrate most from the refracting interface of the optical member by the side of a mask and setting to d distance in alignment with the optical axis to the refracting interface of the optical member in which the aspheric surface is most formed from the refracting interface of the optical member by the side of a mask of projection optics of projection optics, it is more desirable to satisfy the following conditions (3).

(3) The $0.37 \cdot 0 \leq d/D \leq 0.37$ above-mentioned (3) type specifies the optimal location of the aspheric surface over the projection optics which can amend the distortion and the image surface gryposis as high order aberration good.

[0019] If the upper limit and minimum of the above-mentioned (3) formula are exceeded, since it becomes difficult to amend the distortion and the image surface gryposis as high order aberration good, it is not desirable. As for especially the aspheric surface formed in the refracting interface within projection optics in order to amend the high order image surface gryposis to fitness more, it is more desirable to be prepared in the location with which are satisfied of the following (4) types.

(4) $0.05 \leq d/D \leq 0.37$ -- in order to amend a high order distortion with more sufficient balance again, as for the aspheric surface formed in the refracting interface within projection optics, it is more desirable to be prepared in the location with which are satisfied of the following (5) types.

(5) When the aspheric surface by this invention described more than by $0 \leq d/D \leq 0.14$ is a configuration symmetrical with rotation to an optical axis The distance which the aspheric surface set the height from an optical axis to h, and met the optical axis from the point on the aspheric surface in height h from an optical axis to the tangential plane in lens top-most vertices X (h), It is [radius of curvature / of paraxial / constant / r and / cone] Cn about n and the n-th aspheric surface multiplier in k and the natural number. When carrying out, it can express

by the degree type (6).

[0020]

$$X(h) = A/[1+(1-kA/r)^0.5]$$

$$+ C1 h1 + C2 h2 + C3 h3 + C4 h4 + \dots + Cn hn \quad A = h2 / r \quad (6)$$

Moreover, by making the oddth aspheric surface multiplier of the above-mentioned (6) formula into zero, the aspheric surface by this invention can also be expressed, as shown in following (6).

[0021]

$$X(h) = A/[1+(1-kA/r)^0.5]$$

$$+ C2 h2 + C4 h4 + C6 h6 + C8 h8 + C10 h10 + \dots + C2i h2i \quad A = h2 / r \quad (7)$$

However, for the distance and r in alignment with the optical axis from the point on the aspheric surface [in / h from an optical axis to height, and / in X(h) / height h from an optical axis] to the tangential plane in lens top-most vertices, the radius of curvature of paraxial and k is [natural number and C2i of a cone constant and i] 2i order aspheric surface multipliers.

[0022] Here, when it constitutes an aspheric surface configuration symmetrical with rotation to an optical axis, as for the aspheric surface by this invention, it is desirable to consider as the configuration which considered the high order term (high order term in the time of making i into the natural numbers from at least 1 to 6 by the high order term in the time of making n into the natural numbers from at least 1 to 12 by the above-mentioned (6) formula and the above-mentioned (7) formula) to the 12th [at least] order. It enables this to amend the high order aberration which remains in projection optics.

[0023] Moreover, it cannot be overemphasized that the aspheric surface by this invention may consist of configurations of rotation asymmetry not only to the symmetry of revolution but to an optical axis to the optical axis shown by the above-mentioned (6) formula and (7) formulas. Now, it explains, referring to an accompanying drawing about the example by this invention next. It is drawing showing the appearance of the aligner which equipped drawing 1 with projection optics PL.

[0024] As shown in drawing 1, the mask (reticle) R as the projection original edition with which the predetermined circuit pattern was formed in the body side of projection optics PL is arranged, and Mask R is held in the mask stage RS. On the other hand, the wafer W with which the resist was applied is arranged as a photosensitive substrate in the image surface of projection optics PL, and this wafer W is held on the wafer stage WS where it moves two-dimensional in the field which intersects perpendicularly with the optical axis Ax of projection optics. Further, this wafer stage WS it not only moves two-dimensional on it in the field which intersects perpendicularly with the optical axis Ax of projection optics, but in order to make the image surface (exposure side) of projection optics PL, and the front face of Wafer W agree (focus) It is prepared in the method Ax of an optical axis of projection optics movable, and a focus with the image surface (exposure side) of projection optics PL and the front face of Wafer W is detected in optical system by the oblique incidence automatic focus system (AF1, AF2) arranged in the slanting upper part of the wafer stage WS.

[0025] An oblique incidence automatic focus system detects the focus condition of the image surface (exposure side) of projection optics PL, and the front face of Wafer W in photoelectricity by detecting the location of the light received by the detecting element AF 2, in case the incident light from a projection area AF 1 is reflected on the front face of Wafer W. In addition, it moves two-dimensional by the interferometer which measures the location of a mask stage RS, and the drive system MR containing ******, and a mask stage RS moves in the direction of an optical axis Ax on the wafer stage WS at a two-dimensional migration list by the interferometer which measures the location of the wafer stage WS, and the drive system MW containing a drive motor. And a control system MC controls the amount of drives of a drive system MW based on the positional information of the wafer stage WS from the interferometer inside the drive system MW which measures the location of the wafer stage WS while controlling the amount of drives of a drive system MR based on the positional information of the wafer stage WS from the interferometer inside the drive system MR which measures the location of a mask

stage RS. Furthermore, the control system MC is performing control of the location in the direction which met the optical axis Ax of the wafer stage WS based on the output from an oblique incidence automatic focus system (AF1, AF2) through the drive system MW.

[0026] Moreover, the illumination-light study system IS for illuminating Mask R to homogeneity is formed above Mask R, and it is 248.4nm in the interior of this illumination-light study system. The excimer laser which oscillates the light of exposure wavelength is prepared. And the laser light supplied from that excimer laser forms the lighting field of the shape of a predetermined rectangle on a mask, the light source image of an excimer laser is formed in the location of aperture-diaphragm AS established in the pupil location of projection optics PL at this time, and the so-called Koehler illumination is made. Thus, the image of the mask R by which homogeneity lighting was carried out is exposed on Wafer W through projection optics PL by Koehler illumination (imprint).

[0027] And if exposure of the pattern on the mask R in a certain shot field on Wafer W is completed, a wafer stage will be moved to the shot field of the next door on the wafer W, exposure in the next shot field will be performed, and exposure will be performed by the so-called step-and-repeat method exposed by carrying out sequential migration of the wafer stage WS further for the exposure to the shot field to a next door.

[0028] In addition, in this invention, as shown in drawing 19, in case the pattern on Mask R is exposed on a wafer through projection optics PL, for example, without restricting to the aligner of a step-and-repeat method, a mask stage RS and the wafer stage WS can be relatively applied to migration, i.e., the scanning aligner which is made to move Mask R and Wafer W and carries out scan exposure. As for the scanning aligner in this case, it is desirable to consider as the configuration which illuminates Mask R top by the exposure light from the illumination-light study system IS in the shape of a slit (the shape of a rectangle) and the lighting field IF which becomes circular, and forms the shape of a slit (the shape of a rectangle) and the exposure field EF which becomes circular on Wafer W by this.

[0029] The wafer which passed through the process of exposure by the above aligner passes through the process of resist removal of removing the unnecessary resist after the process of etching of removing parts other than the resist developed since it passes the process to develop, and the process of etching etc., and a wafer process is termination *****. And finally termination of a wafer process manufactures semiconductor devices (LSI etc.) like an actual erector through each process, such as dicing which was able to be burned and which cuts and chip-izes a wafer for every circuit, BONDIINGU which gives wiring etc. to each chip, and packaging [PATTEJINGU / for every chip / packaging]. In addition, although the example which manufactures a semiconductor device according to the photolithography process in the wafer process which used the projection aligner was shown above, a liquid crystal display component, the thin film magnetic head, and image sensors (CCD etc.) can be manufactured as a semiconductor device according to the photolithography process using a projection aligner.

[0030] Although a semiconductor device etc. can be manufactured according to the photolithography process by the projection aligner with the *** configuration shown in the above drawing 1, it becomes important at a photolithography process that the projection optics of the projection aligner which projects the pattern of Mask R on a wafer has high optical-character ability. Then, it explains, referring to drawing 2 R> 2 about the adjustment approach of the projection optics in this invention in the time of manufacturing the projection optics for projection aligners.

[0031] Drawing 2 is drawing showing the procedure about the adjustment approach at the time of the projection optics for projection aligners by this invention manufacturing.

[Step 1] At step 1, first, as shown in drawing 4, the lens-barrel which contains the maintenance unit which becomes each lens element (L1-L5) as each optical member which constitutes projection optics PL according to the design value by predetermined design lens data, and a list from the maintenance frame holding each lens, and a lens element and a maintenance frame is manufactured. Namely, the radius of curvature to which each lens element (L1-L5) follows a predetermined design value from a predetermined optical material using a well-known lens

processing machine, respectively, The lens-barrel which contains the maintenance unit which consists of a maintenance frame which is processed so that it may have shaft top thickness, and holds each lens, and a lens element and a maintenance frame is processed into the configuration which has a predetermined dimension from predetermined maintenance ingredients (stainless steel, brass, ceramic, etc.) using a well-known metal processing machine etc., respectively.

[Step 2] The field configuration of the lens side of each lens element (L1-L5) which constitutes the projection optics PL manufactured at step 1 from a step 2 is measured using the interferometer of for example, the Fizeau mold. One example of the interferometer of the Fizeau mold which measures the configuration of the front face of an optical element is shown in drawing 6 . It is 633nm as shown in drawing 6 . helium-Ne gas laser and 363nm which emits the light of wavelength lambda Ar laser and 248nm which emits the light of wavelength lambda The light from the laser light sources 11, such as Ar laser higher-harmonic-wave-ized by wavelength lambda, reflects a beam splitter 13 through a lens 12, and is changed into the parallel flux of light by the collimator lens 14. The parallel flux of light irradiates the specimen plane (lens side) S of the lens 18 as specimen through a condenser lens 15. Here, the reference side is formed in the condenser lens 15, the one section of light is reflected in respect of reference of a condenser lens 15, and the remaining light passes a condenser lens 15 and is reflected by the specimen plane S. the configuration [wave front / of these reflected lights] corresponding to the configurations of a reference side and a specimen plane S respectively -- ** -- it becomes. By following the same optical path and returning, these reflected lights are piled up mutually and image formation is carried out in respect of the image pick-up of the image pick-up equipments 17, such as CCD, through a collimator lens 14, a beam splitter 13, and the image formation lens 16. At this time, the interference fringe by interference of both the reflected lights is formed in the image pick-up side of image pick-up equipment 17, and the configuration of a specimen plane S can be correctly searched for by measuring that interference fringe. In addition, it is well-known to search for the configuration of the front face (lens side) of optical elements, such as a lens, using the interferometer of the Fizeau mold, and this thing is indicated in JP,62-126305,A, JP,6-185997,A, etc.

[0032] Like the above, measurement of the field configuration of an optical element which used the interferometer of the Fizeau mold is performed about all the lens sides of each lens element (L1-L5) which constitutes projection optics PL. And the memory section of the operation systems 7, such as a computer and a computer, is made to memorize the each measured result through the input systems 6, such as a console, as shown in drawing 3 .

[Step 3] After measurement of the field configuration of all the lens sides of each lens element (L1-L5) which constitutes the projection optics PL in step 2 is completed, for example, the maintenance frame (2A-2E) which holds optical elements (L1-L5), such as the optical unit by which processing manufacture was carried out according to the design value, i.e., a lens etc., and the optical element (L1-L5) of those as shown in drawing 4 -- each of five optical units -- *****. And making a washer (3A-3E) intervene one by one through up opening 1a of a lens-barrel 1, it finishes setting up five optical units setting up was finished so that it may drop into a lens-barrel 1. And the optical unit (L5, 2E) first dropped into the lens-barrel 1 is supported through washer 3E in lobe 1b formed at the tip (wafer side) of a lens-barrel 1, and the process incorporated by holding all optical units in a lens-barrel 1 completes it. It is parallel like this assembler, and the information about spacing of the optical surface (lens side) of each lens element is measured using tools (micrometer etc.), considering the thickness of the washer (3A-3E) contained in a lens-barrel with a maintenance unit. And it asks for spacing of the optical surface (lens side) of each final lens element of the projection optics PL in the phase as for which step 3 carried out setting-up process completion, doing a measurement activity with the setting-up activity of projection optics by turns.

[0033] Thus, it assembles and the memory section of the operation systems 7, such as a computer and a computer, is made to memorize in process or the measurement result about spacing between the optical surfaces (lens side) of each lens element of the projection optics PL in the time of assembly completion through the input systems 6, such as a console, as shown in

drawing 3 . In addition, on the occasion of the process which more than incorporates, an optical unit may be adjusted if needed. An optical element is made for relative spacing in the direction of an optical axis between optical elements to incline to change or an optical axis at this time, for example, exchange of a washer (3A-3E). Moreover, by constituting a lens-barrel 1 so that the tip of the screw screwed through the internal thread part which penetrates the side face of a lens-barrel 1 may contact a maintenance frame, and moving the screw through tools, such as a driver, between attachment components may be shifted in the direction which intersects perpendicularly with an optical axis, and eccentricity etc. may be adjusted. This thing is indicated by JP,7-35963,A.

[0034] Moreover, a maintenance frame (2A-2E) may be the structure of carrying out coincidence maintenance not only of the thing holding one optical element but two or more optical elements, namely, holding a lens group. Moreover, as shown in drawing 5 , you may finish setting up projection optics PL by the so-called division lens-barrel method which holds an optical element by the direct lens-barrel (4A-4E) for every optical element and every lens group, accumulates each of that lens-barrel (4A-4E), making a washer (5A-5D) etc. intervene, and assembles optical system.

[Step 4] Next, at step 4, as shown in drawing 4 or drawing 5 , the aberration of a low degree which remains in the projection optics PL composed at step 3 is measured.

[0035] It specifically attaches in the body of a *** projection aligner (or inspection machine with the same configuration as the body of a projection aligner) which shows projection optics to drawing 1 once, and various kinds of aberration (spherical aberration, comatic aberration, astigmatism, image surface gryposis, distortion aberration, etc.) is measured using the *** test mask (TR1, TR2) shown in drawing 7 and drawing 8 . While attaching the projection optics PL to be examined in the *** equipment (or inspection machine with the configuration shown in drawing 1) shown in drawing 1 as an example of aberration measurement in measurement of the image surface gryposis, the test mask TR1 shown in drawing 7 is held to a mask stage RS. The test mask TR1 at this time has the test pattern field PA 1 in which two or more marks were formed in XY flat surface, and the protection-from-light band latest starting time formed around that. the direction mark M1 of Y which has a predetermined pitch in the test pattern field PA 1 for example, in the direction of Y The direction mark M2 of X which has a predetermined pitch in the direction of X The mark group with four marks with the direction mark of slant (M3 and M4) which has a predetermined pitch along the direction of 45 slant to the XY direction is formed in 17 places.

[0036] The test mask TR1 can be burned on a shot field wafer top predetermined [as a photosensitive substrate] through the projection optics PL to be examined using the *** test mask TR1 shown in drawing 7 . And the wafer stage WS is moved two-dimensional, the exposure field of projection optics is located in a different shot field from the above-mentioned predetermined shot field, only the specified quantity moves the wafer stage WS along the direction of an optical axis Ax using an oblique incidence automatic focus system (AF1, AF2), and the image of the test mask TR1 can be burned on the different shot field concerned. Thus, two-dimensional migration of the wafer stage WS, migration of the wafer stage WS in the direction of an optical axis, and actuation of exposure are repeated, and the test mask TR1 in two or more locations which met in the direction of an optical axis of projection optics PL is burned. In addition, when the number of shot fields is not settled in one wafer, you may also insert the actuation which lays another wafer on the wafer stage WS.

[0037] Next, by asking for the location (the location in an exposure field, and location in the direction of an optical axis) of the best image of each mark about all the wafers that were able to be burned using an electron microscope etc. based on each mark image of the pattern which was actually able to be burned on Wafer W, as shown in drawing 9 , the amount of image surface gryposis of the projection optics PL to be examined is detectable. Here, the image surface gryposis when drawing 9 takes image quantity along an axis of abscissa and takes the amount of defocusing along an axis of ordinate is shown, and the curve a of drawing 9 shows the image surface gryposis which remains in the projection optics PL composed at step 3. This curve a

plots the location of the best mark image as a result of actually carrying out proof print of the wafer W and being obtained using the test mask TR1 shown in drawing 7 .

[0038] Moreover, while attaching the projection optics PL to be examined in the *** equipment (or inspection machine with the configuration shown in drawing 1) shown in drawing 1 in measurement of distortion aberration, the test pattern shown in drawing 8 is held to a mask stage RS. The test mask TR2 at this time has the test pattern field PA 2 in which two or more marks were formed in XY flat surface, and the protection-from-light band latest starting time formed around that, and it is formed in that test pattern field PA 2 at 81 places so that the mark (8 0 M zero -M 8) of the rectangular mold for example, on a cross joint may serve as *** regular intervals in the direction of Y at the direction list of X. Then, an actual test pattern can be burned on the wafer as a photosensitive substrate through the projection optics PL to be examined. At this time, a wafer front face sets up the location of the wafer stage WS using an oblique incidence automatic focus system (AF1, AF2) so that it may be located in the best image surface of projection optics PL. And the amount of distortion aberration of the projection optics PL to be examined is detectable by calculating the amount of gaps of each mark location of the pattern which was actually able to be burned, and the ideal location (each mark location by the design value) of each mark which should be burned using an electron microscope etc.

[0039] Here, distortion aberration when drawing 10 takes image quantity along an axis of abscissa and takes the amount of defocusing along an axis of ordinate is shown, and the curve a of drawing 10 shows the image surface gryposis which remains in the projection optics PL composed at step 3. This curve b plots the amount of gaps of each mark location to a design value as a result of actually carrying out proof print of the wafer W and being obtained using the test mask TR1 shown in drawing 7 about each image quantity.

[0040] In addition, although the actually exposed example was described above in order to measure many aberration, image sensors, such as CCD on plane of projection, may be arranged, and the amount of many aberration may be calculated through displays, such as a CRT monitor electrically connected with the image sensor, from the appearance of each mark image of a test mask (TR1, TR2). The memory section of the operation systems 7, such as a computer and a computer, is made to memorize the information about the amount of aberration about many aberration which remains in the measured projection optics PL through the input systems 6, such as a console, in this aberration measurement process, as shown in drawing 3 .

[step 5] -- substep 5a and substep 5b which explain step 5 below -- ** -- it contains, and these substeps 5a and 5b are parallel in step 5, and are performed.

[Substep 5a] In substep 5a, in order to remove the aberration of a low degree which remains in the projection optics PL measured at step 4, projection optics PL is adjusted.

[0041] Adjustment of projection optics PL is preceded. First, the operation systems 7, such as a computer and a computer As shown in drawing 3 , it is based on the information about spacing of the optical surface of each optical element obtained like the assembler of each information memorized by memory circles, i.e., the information about the field configuration of each optical element obtained at step 2, and step 3 etc. The optical master data beforehand memorized by memory circles is corrected, and the optical data in the manufacture process of the actually composed projection optics PL are reproduced. Then, the information about the amount of aberration about many aberration which remains in the projection optics PL acquired at step 4 as information the operation system 7 was remembered to be by memory circles, It is based on the optical data in the manufacture process of the actually composed projection optics PL.

Spacing (it is hereafter called the amount of spacing amendments of an optical surface) of the optical surface of each optical element which aberration can amend is computed, and information, such as the amount of spacing amendments of the optical surface of each optical element, is expressed as the display systems 8, such as a non-illustrated CRT monitor.

[0042] Next, an optical element is made for relative spacing in the direction of an optical axis between optical elements to incline to change or an optical axis based on the amount of spacing amendments of the optical surface of each optical element computed by the operation systems 7, such as a computer, by exchange of the washer inside projection optics PL used as the subject

of examination shown in drawing 4 R> 4 or drawing 5 (3A-3E, 5A-5D). Moreover, between attachment components is shifted in the direction which intersects perpendicularly with an optical axis by constituting so that the tip of the screw screwed through the internal thread part which penetrates the side face of a lens-barrel 1 may contact a maintenance frame, and moving the screw through tools, such as a driver. Aberration of a low degree, such as **** image surface gryposis which adjustment is made, for example, shows projection optics PL to each curve a of drawing 9 and drawing 10 , and distortion aberration, is removed by performing such adjustment technique.

[0043] In addition, on the occasion of adjustment of projection optics PL, the one section or all of projection optics PL is decomposed if needed, exchange of a washer (3A-3E, 5A-5D) or an optical unit is performed, and it finishes setting up projection optics PL again.

[Substep 5b] In this substep 5b, it is parallel to the adjustment process of substep 5a like ****, and the information about spacing of the optical surface (lens side) of each lens element of projection optics PL is searched for. That is, spacing of the optical surface (lens side) of each lens element is measured using tools (micrometer etc.), considering the thickness of the washer (3A-3E, 5A-5D) contained in a lens-barrel with a maintenance unit at the time of the adjustment process of projection optics PL. And it asks for spacing of the optical surface (lens side) of each final lens element of the projection optics PL when the adjustment process of substep 5a is completed, doing the tuning of substep 5a, and the measurement activity of substep 5b by turns.

[0044] thus, it is shown in drawing 3 -- as -- adjustment -- the memory section of the operation systems 7, such as a computer and a computer, is made to memorize in process or the measured result (information about spacing of the optical surface (lens side) of each lens element) which is related with spacing between the optical surfaces (lens side) of each lens element of the projection optics PL in the time of the completion of adjustment through the input systems 6, such as a console

[Step 6] After the aberration of a low degree which remains by projection optics PL in step 5 is removed by adjustment of projection optics PL, it sets to step 6. The manufacture error of an optical element (for example, thing which consists of minute aspheric lenses in which the lens element which consists of spherical lenses with predetermined radius of curvature has minute irregularity according to a manufacture error), Or the high order aberration which the assembly manufacture error produced in the manufacture phase of projection optics unremovable by adjustment of step 3 originates, and remains in projection optics PL is measured.

[0045] Although detailed explanation is omitted since measurement of aberration is the same as step 4 described, it can be burned on the wafer as a photosensitive substrate through the projection optics PL to be examined, for example using a test mask (TR1, TR2). Each high order aberration of the projection optics PL to be examined is detected by inspecting each mark image of the pattern which was actually able to be burned on Wafer W about all the wafers that were able to be burned using an electron microscope etc. For example, aberration with high order drawing 9 , **** image surface gryposis shown in each curve b of drawing 10 , distortion aberration, etc. is measured.

[0046] The memory section of the operation systems 7, such as a computer and a computer, is made to memorize the information about the high order amount of aberration which remains in the measured projection optics PL through the input systems 6, such as a console, in the high order aberration measurement process of this step 6, as shown in drawing 3 .

[Step 7] in order to form the minute aspheric surface which amends the amount of high order aberration which was obtained at step 6, and which remains in at least one of said two or more of the optical members The information on the field configuration of each optical member of projection optics PL, and the information on spacing of the final optical surface between the optical members of the plurality of the projection optics PL in the completion phase of adjustment, It is required to reproduce the manufacture optical data of the projection optics PL at the time of the completion of adjustment at step 5 based on the information about optical designs, such as an optical basic engineering data of projection optics.

[0047] For this reason, step 7 forms the minute aspheric surface which amends the amount of high order aberration which was obtained at step 6, and which remains in at least one of said two or more of the optical members based on the information on the field configuration of each optical member obtained at the above-mentioned step 2, the information on spacing of the optical surface between two or more optical members obtained at the above-mentioned step 5, and the optical design information on projection optics.

[0048] The location of the aspheric surface which can amend each aberration with the high order projection optics PL to be examined by which this step 7 at this time was measured at step 6, After the configuration of the aspheric surface, the 1st substep which determines the number of the aspheric surfaces, and its 1st substep, The optical element which should carry out aspheric surface processing is taken out, and it has the 3rd substep which includes the optical element by which aspheric surface processing was carried out in projection optics PL, and adjusts it after the 2nd substep which performs aspheric surface processing using a lens polish processing machine, and the 2nd substep.

[1st substep] The aspheric surface which can amend each high order aberration of the projection optics PL to be examined measured by the information about spacing of the optical surface (lens side) of each lens element of the projection optics PL when asking first at the information on the field configuration of the lens side of each lens element measured at step 2 and step 6 at which the completion of adjustment was carried out, and the list at step 7 based on the optical design information on projection optics PL is determined.

[0049] For example, the information about each high order aberration of the projection optics PL to be examined measured at step 6 is used for the operation systems 7, such as a computer. Information about the manufacture optical data of the projection optics PL acquired in advance of the adjustment process of step 5 (it is based on the information about spacing of the optical surface of each optical element obtained like the assembler of the information about the field configuration of each optical element obtained at step 2, and step 3 etc.) The information on the optical data in the time of setting up of the corrected projection optics PL is re-corrected, and the optical data in the manufacture process of the projection optics PL after adjustment process completion of step 5 are reproduced.

[0050] In addition, without using the information about the manufacture optical data of the projection optics PL acquired in advance of the adjustment process of step 5 The information on the field configuration of the lens side of each lens element measured at step 2, The information about spacing of the optical surface of each optical element obtained like the assembler of step 3, The optical data in the manufacture process of the projection optics PL after adjustment process completion of step 5 may be reproduced newly using the information about spacing of the optical surface (lens side) of each lens element of the projection optics PL when asking at step 5 at which the completion of adjustment was carried out. Moreover, an assembler makes the memory section of the operation systems 7, such as a computer computer, memorize the hysteresis about spacing or spacing variation of an optical surface (lens side) of projection optics PL when passing through an adjustment process through input systems, such as a console. [of each lens element] It may ask for spacing of the optical surface (lens side) of each lens element of the projection optics PL when carrying out the completion of adjustment from the hysteresis, and it may be used as information on the field configuration of the lens side of each lens element.

[0051] Next, operation systems 7, such as a computer, perform ray tracing, and determine the number of the location of the minute aspheric surface which can amend each high order aberration which remains in projection optics PL, a configuration, and the aspheric surfaces based on the information about the amount of aberration about many high order aberration which remains in the projection optics PL acquired at step 6 as information remembered to be manufacture optical data at the time of the reproduced completion of adjustment like **** by memory circles.

[2nd substep] Now, in order to form in projection optics PL the minute aspheric surface searched for by ray tracing using the operation systems 7, such as a computer, the one section

or all of projection optics PL is decomposed if needed, and the optical unit which should perform aspheric surface processing is taken out. Then, after the optical element in an optical unit takes out, a lens polish processing machine performs aspheric surface processing to the processing side of an optical element.

[0052] Drawing 11 shows the configuration of a lens polish processing machine, and inputs into a control section 20 the aspheric surface processing data computed using the operation systems 7, such as a computer, through the input system 31 of a lens polish processing machine. As shown in drawing 11, the lens element (optical element) 10 as a processed object is laid in the XY direction on the movable migration stage 21, and the edge of that is in contact with for example, pin 21a. In addition, although drawing 11 shows the example to which the refractive power of the optical surface of a lens side etc. set the lens of very weak refractility as the processed object, the refractive power of the optical surface of a lens side etc. can also set the plane-parallel plate of the light transmission nature of zero as the processed object. Furthermore, although it is good also considering the lens of refractility with the strong refractive power of the optical surface of a lens side etc. as a processed object, when a manufacture top is taken into consideration, it is desirable for the refractive power of the optical surface of a lens side etc. to make taper faculty material applicable to processing as much as possible.

[0053] Moreover, in order to move a stage 21 in the XY direction two-dimensional, the mechanical component 22 is controlled by the control section 20. In case a stage 21 is moved through a mechanical component 22, in order to detect the location of the XY direction of a stage 21, the location detecting element 30 which consists of an encoder, an interferometer, etc. is formed in the left end side of a stage 21, and the detecting signal from this location detecting element 30 is transmitted to a control section 20.

[0054] Moreover, the polish pan 23 is attached in the end of a revolving shaft 25 through the attaching part 24, and is pivotable considering the Z direction in drawing as a shaft. The motor 26 controlled by the control section 20 is attached in the other end of this revolving shaft 25. The bearing 27 supported for a revolving shaft 25, enabling free rotation is formed in the Z direction movable to the supporter 28 fixed to the non-illustrated body. The motor 29 controlled by the control section 20 is attached in this supporter 28, and a bearing 27 moves along with a Z direction according to an operation of this motor 29, as a result the polish pan 23 moves to a Z direction. In addition, the sensor (un-illustrating) for detecting the contact pressure of the polish pan 23 and the lens element 10 as a workpiece is formed in the attaching part 24 holding the polish pan 23, and the output about the contact pressure from this sensor is transmitted to a control section 29.

[0055] When actuation of the lens polish processing machine in step 5 is explained, first The amount of processings of the minute aspheric surface about the optical element which can amend each high order aberration of projection optics PL as mentioned above, That is, while inputting into a control section 20 the aspheric surface processing data computed using the count systems 7, such as a computer, through the input system 31 of a lens polish processing machine, the optical element 10 as a workpiece is held on the stage 21 of the lens polish processing machine in drawing 11 .

[0056] Next, it is moved along the XY direction of a stage 21 through a mechanical component 22, a control section 20 rotating the polish pan 23 through a motor 26. That is, the polish pan 23 moves so that it may trace along with processing side 10a of the optical element 10 as a workpiece. At this time, the amount of polishes in processing side 10a is determined by the contact pressure of processing side 10a and the polish pan 23, and the residence time of the polish pan 23.

[3rd substep] If processing by the above lens polish processing machine is completed, as for the optical element 10 as a workpiece, a maintenance frame will be attached after an antireflection film is given according to a vacuum evaporationo process etc. And the optical unit which finally holds the optical element by which aspheric surface processing was carried out with the lens polish processing machine is included in projection optics PL. At this time, an optical element is

made to incline and it shifts in the direction which intersects between attachment components perpendicularly with an optical axis to fine tuning or an optical axis in relative spacing in the direction of an optical axis between optical elements by exchange of the washer inside projection optics PL used as the subject of examination shown in drawing 4 or drawing 5 if needed (4A-4E, 5A-5D). By performing such adjustment technique, aberration with high order **** image surface gryposis which adjustment is made, for example, shows projection optics PL to drawing 9 and drawing 10 , distortion aberration, etc. is removed, and manufacture of the projection optics PL with the desired image formation engine performance is attained.

[0057]

[Example] Next, the projection optics PL manufactured by each above step is explained concretely. It is 248.4nm as the light source arranged inside illumination-light study equipment IS at drawing 12 . The example of the lens configuration of the projection optics when considering as the excimer laser which supplies light with the exposure wavelength lambda is shown.

[0058] The 1st lens group G1 in which the projection optics in this example has forward refractive power in order [side / as the 1st body / reticle R] as shown in drawing 12 , It has the 6th lens group G6 for forward refractive power with the 2nd lens group G2 with negative refractive power </SUB>, 3rd lens group G3 with forward refractive power, the 4th lens group G4 with negative refractive power, and the 5th lens group G5 with forward refractive power.

[0059] First, the 1st lens group with forward refractive power has mainly contributed to amendment of distortion, maintaining tele cent rucksack nature, and, specifically, has amended a negative distortion which is made to generate a forward distortion by the 1st lens group, and is generated by two or more lens groups located in the 2nd body side rather than this 1st lens group with sufficient balance. The 4th lens group with the 2nd lens group and negative refractive power with negative refractive power mainly contributes to amendment of the PETTSU bar sum, and is attaining flattening of the image surface. By the 3rd lens group with the 2nd lens group and forward refractive power with negative refractive power, the reverse looking-far system is formed in these two lens groups, and it has contributed to reservation of the back focus (most distance [Projection optics] from the optical surface of the lens side by the side of the 2nd body etc. to the 2nd body) of projection optics. Especially since the 5th lens group and the same forward refractive power with forward refractive power are enough corresponded to that the 6th lens group suppresses generating of distortion, and high NA-ization by the side of the 2nd body, generating of spherical aberration has mainly been contributed to stopping as much as possible.

[0060] At this time, it is the focal distance of the 1st lens group f1 It carries out. The focal distance of the 2nd lens group f2, When setting [the focal distance of the 3rd lens group / the focal distance of f3 and the 4th lens group / the focal distance of f4 and the 5th lens group] distance from f6 and the 1st body side to the 2nd body side to L for the focal distance of f5 and the 6th lens group, it is more desirable to satisfy following conditions (8) – (11).

(8) $0.1 < f1/f3 < 17$ (9) $0.1 < f2/f4 < 14$ (10) $0.01 < f5 / L < 0.9$ (11) Focal distance f1 of the 1st lens group of refractive power forward on $0.02 < f6 / L < 1.6$ conditions (8) Focal distance f3 of the 3rd lens group of forward refractive power The optimal refractive-power (power) allocation with the optimal ratio, i.e., the 1st lens group and the 3rd lens group, is specified. This condition (8) is for mainly amending distortion with sufficient balance, and if the minimum of this condition (8) is exceeded, since the refractive power of the 3rd lens group will become weak relatively to the refractive power of the 1st lens group, a negative distortion generates it greatly. Moreover, if the upper limit of conditions (8) is exceeded, since the refractive power of the 1st lens group will become weak relatively to the refractive power of the 3rd lens group, a negative distortion occurs greatly.

[0061] Focal distance f2 of the 2nd lens group of refractive power negative on conditions (9) Focal distance f4 of the 4th lens group of negative refractive power The optimal refractive-power (power) allocation with the optimal ratio, i.e., the 2nd lens group and the 4th lens group, is specified. Mainly making the PETTSU bar sum small and securing the large

exposure field, this condition (9) is for amending a curvature of field good, and if the minimum of this condition (9) is exceeded, since the refractive power of the 4th lens group will become weak relatively to the refractive power of the 2nd lens group, the forward PETTSU bar sum generates it greatly. Moreover, if the upper limit of conditions (9) is exceeded, since the refractive power of the 2nd lens group will become weak relatively to the refractive power of the 4th lens group, the forward PETTSU bar sum occurs greatly. In addition, it is $0.8 < f_2 / f_4$, using the lower limit of the above-mentioned conditions (9) as 0.8, in order to strengthen refractive power of the 4th lens group relatively to the refractive power of the 2nd lens group and to amend the PETTSU bar sum with more sufficient balance under the large exposure field. Carrying out is desirable.

[0062] Focal distance f_5 of the 5th lens group of refractive power forward on conditions (10) The optimal ratio with the distance (length between object images) L to the 1st body (reticle etc.) and the 2nd body (wafer etc.) is specified. This condition (10) is for amending spherical aberration, distortion, and the PETTSU bar sum with sufficient balance, maintaining a big numerical aperture. If the minimum of this condition (10) is exceeded, the refractive power of the 5th lens group will become large too much, and not only a negative distortion but negative spherical aberration will occur serious by this 5th lens group. If the upper limit of this condition (10) is exceeded, refractive power of the 5th lens group cannot become weak too much, and the refractive power of the 4th lens group of negative refractive power cannot become weak inevitably in connection with this, either, consequently the PETTSU bar sum cannot be amended good.

[0063] Focal distance f_6 of the 6th lens group of refractive power forward on conditions (11) The optimal ratio with the distance (length between object images) L from the 1st body (reticle etc.) to the 2nd body (wafer etc.) is specified. This condition (11) is for suppressing generating of high order spherical aberration and a negative distortion, maintaining a big numerical aperture. If the minimum of this condition (11) is exceeded, a distortion negative by the 6th lens group itself will occur greatly, and if the upper limit of this condition (11) is exceeded, high order spherical aberration will occur.

[0064] now -- drawing 11 -- having been shown -- a book -- an example -- projection optics -- PL -- being related -- an item -- a value -- the following -- a table -- one -- hanging up -- moreover -- a table -- one -- being shown -- projection optics -- PL -- being related -- the above -- conditions -- (-- eight --) - (-- 11 --) -- conditions -- correspondence -- a value -- Table 2 -- hanging up . A left end figure expresses the sequence from a body side (reticle side). r However, the radius of curvature of a lens side, For a lens spacing and n , the exposure wavelength λ is [d] 248.4nm. Synthetic quartz SiO_2 which can be set Refractive index, d_0 The 1st lens group G_1 most from the 1st body (reticle) Distance to the lens side (the 1st lens side) by the side of a body (reticle side), The 6th lens group G_6 most B_f The distance from the lens side by the side of an image (wafer side) to the image surface (wafer side), B the numerical aperture by the side of the image of projection optics, and L for the projection scale factor of projection optics, and NA The length between object images from a body side (reticle side) to the image surface (wafer side), f_1 The focal distance of the 1st lens group G_1 , and f_2 The focal distance of the 2nd lens group G_2 , and f_3 The focal distance of 3rd lens group G_3 , and f_4 The focal distance of the 4th lens group G_4 , and f_5 The focal distance of the 5th lens group G_5 , and f_6 The focal distance of the 6th lens group G_6 is expressed.

[0065]

[Table 1]

d0 = 105.99385

B = 1 / 5

NA = 0.55

B f = 28.96856

L = 1200

	r	d	n
1	723.32335	28.00000	1.50839 (L ₁₁)
2	-571.27029	2.00000	
3	-8470.94995	20.00000	1.50839 (L ₁₂)
4	324.13159	7.92536	
5	360.44110	28.00000	1.50839 (L ₁₃)
6	-432.97069	1.04750	
7	397.04484	27.00000	1.50839 (L ₁₄)
8	-825.96923	0.97572	
9	214.74004	31.00000	1.50839 (L ₂₁)
10	110.51892	24.04713	
11	229.41181	26.00000	1.50839 (L ₂₂)
12	-396.52854	1.10686	
13	-1014.34000	17.00000	1.50839 (L ₂₃)
14	137.90605	18.76700	
15	-418.55207	12.90000	1.50839 (L ₂₄)
16	138.89479	26.88549	
17	-133.71351	15.00000	1.50839 (L ₃₁)
18	561.35918	52.53782	
19	1381.31000	35.00000	1.50839 (L ₃₂)
20	-188.69074	14.91509	
21	-134.03345	22.80000	1.50839 (L ₃₃)
22	-198.69180	2.79782	
23	-3029.37000	27.00000	1.50839 (L ₃₄)
24	-333.96362	2.87255	
25	905.53484	28.00000	1.50839 (L ₃₅)
26	-611.80005	2.49780	
27	254.70879	30.00000	1.50839 (L ₃₆)
28	3936.53000	1.64701	
29	239.51669	31.00000	1.50839 (L ₃₇)
30	-1238.94000	5.60527	
31	-2379.42001	21.00000	1.50839 (L ₄₁)
32	150.43068	9.76890	
33	209.21387	17.00000	1.50839 (L ₄₂)
34	149.67785	31.54706	
35	-199.55198	15.90000	1.50839 (L ₄₃)
36	341.76300	57.70880	
37	-170.75300	18.00000	1.50839 (L ₄₄)
38	-3700.60999	6.28784	
39	-1025.75000	23.00000	1.50839 (L ₅₁)

40	-212.37919	1.14438	
41	-3009.97000	23.00000	1.50839 (L ₅₃)
42	-312.33647	2.92283	
43	401.05778	37.00000	1.50839 (L ₅₃)
44	-361.42967	12.43498	
45	-231.63315	27.00000	1.50839 (L ₅₄)
46	-319.48896	1.10071	
47	355.64919	25.00000	1.50839 (L ₅₅)
48	3678.53000	4.83032	
49	177.43364	32.00000	1.50839 (L ₅₆)
50	553.83964	3.29194	
51	137.68248	39.90000	1.50839 (L ₅₇)
52	330.86342	9.82671	
53	587.42747	23.00000	1.50839 (L ₅₈)
54	81.23164	7.04896	
55	93.74477	71.00000	1.50839 (L ₆₁)
56	1555.42999		

[0066]

[Table 2]

[The value corresponding to conditions about conditions (8) – conditions (11)]

As shown in $f_1/f_3 = 1.58f_2/f_4 = 1.63f_5/L = 0.0923f_6/L = 0.161$ drawing 12, the projection optics of Table 1 The 1st lens group G1 which has forward refractive power in order [side / as the 1st body / reticle R], The 2nd lens group G2 with negative refractive power, and 3rd lens group G3 with forward refractive power, With the 4th lens group G4 with negative refractive power, and the 5th lens group G5 with forward refractive power, it has the 6th lens group G6, has become a tele cent rucksack mostly about forward refractive power, at the body and image side (Reticle R side) (Wafer W side), and has a contraction scale factor. In addition, for the numerical aperture NA by the side of 1200 and an image, 0.55 and the projection scale factor B is [length between object images (distance from a body side to the image surface, or distance from Reticle R to Wafer W) L / the diameter of the exposure field on 1/5 and Wafer W of the projection optics of each example shown in drawing 12] 31.2, respectively.

[0067] If the concrete lens configuration of the projection optics shown in drawing 12 is explained, the 1st lens group G1 first has the positive lens (lens of both the convex configuration) L11 of the configuration where the convex was turned to the image side, the negative lens L12 of the meniscus configuration where the convex was turned to the body side, and two positive lenses (L13, L14) of both the convex configuration, sequentially from the body side. And negative meniscus lens (front lens) L2F which the 2nd lens group G2 has been arranged most at the body side, and turned the concave surface to the image side, Negative meniscus lens (back lens) L2R which has been arranged most at the image side and turned the concave surface to the body side, It consists of middle lens group G2M which are arranged between negative meniscus lens L2F in the 2nd lens group G2 most located in a body side, and negative meniscus lens L2R in the 2nd lens group most located in an image side, and have negative refractive power.

[0068] The middle lens group G2M Sequentially from a body side, the positive lens LM1 of both the convex configuration (the 1st lens), The negative lens LM2 to which the field of strong curvature was turned by the image side (the 2nd lens), It consists of a negative lens (the 3rd lens) LM3 of both the concave configuration, a negative lens (the 4th lens) LM4 to which the field of strong curvature was turned by the body side, and a positive lens (the 5th lens) LM5 to which the field of strong curvature was turned by the image side.

[0069] Moreover, the positive lens L31 to which 3rd lens group G3 turned the field of strong curvature by the image side (positive meniscus lens), The positive lens L32 of both the convex configuration, and the positive lens L33 which turned the convex to the body side (positive

meniscus lens), It consists of positive lenses L34 to which the field of strong curvature was turned by the body side. The 4th lens group G4 It consists of the negative lens L41 which turned the concave surface to the image side, a negative meniscus lens L42 which turned the concave surface to the image side, a negative lens L43 of both the concave configuration, and a negative lens L44 which turned the concave surface to the body side.

[0070] Here, aperture-diaphragm AS is arranged in the optical path between the concave surface by the side of the image of the negative lens L41 in the 4th lens group G4, and the concave surface by the side of the body of a negative meniscus lens L44. The positive meniscus lens L51 with which the 5th lens group G5 turned the convex to the image side, The positive lens L52 to which the field of strong curvature was turned by the image side, and the positive lens L53 of both the convex configuration, The negative meniscus lens L54 which turned the concave surface to the body side, and the positive lens L55 to which the field of strong curvature was turned by the body side, The positive meniscus lens L56 which turned the convex to the body side, and the positive lens (positive meniscus lens) L57 to which the field of strong curvature was turned by the body side, Consisting of negative lenses (negative meniscus lens) L58 which turned the concave surface to the image side, the 6th lens group G6 consists of only heavy-gage positive lenses L61 which turned the convex to the body side.

[0071] Here, in the 1st lens group G1, since the lens side by the side of the image of the negative lens L12 of the meniscus configuration where the convex was turned to the body side, and the lens side by the side of the body of the positive lens L13 of both the convex configuration have comparable curvature and are comparatively close, these two lens sides have amended a high order distortion. Moreover, since front lens L2F with the negative refractive power of the 2nd lens group G2 arranged most at a body side consists of meniscus configurations where the concave surface was turned to the image side, Generating of comatic aberration can be mitigated and it is middle lens group G2M. Since the 1st lens LM1 with forward refractive power consists of both convex configurations where the convex was turned not only to the configuration where the convex was turned to the image side but to the body side, generating of the spherical aberration of a pupil can be suppressed. Moreover, middle lens group G2M Since it has the concave surface of back lens L2R in which the 5th lens LM5 with forward refractive power has the negative refractive power arranged at the image side, and the convex which counters, astigmatism can be amended.

[0072] Moreover, by the 4th lens group G4, the negative lens L41 which turned the concave surface to the image side at the body side of a negative lens (negative lens of both the concave configuration) L43 is arranged, and since it is the configuration which arranges the negative lens L44 to which the concave surface was turned at the body side at the image side of a negative lens (negative lens of both the concave configuration) L43, the PETTSU bar sum can be amended, suppressing generating of comatic aberration. Moreover, by arranging aperture-diaphragm AS between the concave surface by the side of the image of the negative lens L41 in the 4th lens group G4, and the concave surface by the side of the body of a negative lens L44 Since it can constitute without seldom breaking down symmetry applying a contraction scale factor for the lens group from 3rd lens group G3 to the 6th lens group G6 somewhat focusing on aperture-diaphragm AS, generating of unsymmetrical aberration especially comatic aberration, or distortion can be controlled.

[0073] Moreover, it is ***** to have the convex to which the positive lens L53 in the 5th lens group G5 counters a negative meniscus lens L54, and to suppress generating of the high order spherical aberration accompanying a raise in NA good, since it is both the convex configuration where the lens side of a negative meniscus lens L54 and the opposite side is also a convex. Now, the example about the process which manufactures next the projection optics PL based on the basic engineering data shown in Table 1 is explained.

[Step 1] As shown in drawing 2 , the lens-barrel which contains the maintenance unit which becomes each lens list which constitutes the projection optics PL which fills with the above-mentioned step 1 the lens data shown in Table 1 from the maintenance frame and lens holding each lens, and a maintenance frame is manufactured. That is, the lens-barrel which

contains the maintenance unit which consists of the maintenance frame and the lens which each lens is processed so that it may have predetermined radius of curvature and predetermined shaft top thickness from a predetermined optical material (quartz) using a well-known lens processing machine, respectively, and hold each lens, and a maintenance frame is processed into the configuration which has a predetermined dimension from predetermined maintenance ingredients (stainless steel, brass, ceramic, etc.) using a well-known metal processing machine etc., respectively.

[Step 2] Next, at step 2, in order to acquire the processing information on a lens side exact about whether the lens side which should be processed into the spherical surface has formed the minute aspheric surface according to the processing error of a lens side etc., the configuration of the lens side of each lens is measured about the lens side of all the lenses processed at step 1 using the interferometer of the **** Fizeau mold shown in drawing 6 . The measurement result is memorized through the input systems 6, such as a console, by the memory section in the operation systems 7, such as a computer and a computer, as shown in drawing 3 . In addition, it is good also as a configuration which connects electrically the field configuration calculation section and the operation system 7 which were prepared in the interior of the interferometer of the Fizeau mold, and inputs the output from the field configuration calculation section into the memory section of the operation system 7.

[0074] Here, an example about the data of the configuration of the measured lens side is shown in Table 3. As shown in Table 3, the page [29th] lens side of r1 -r3, r5, r6, r9 -r15, r17, r19, r21-r23, r31, r34, r35, r37, r45-r47, r49-r52, and r54 does not turn into a spherical-lens side, but is the aspheric surface according to the processing error. In addition, the lens side is processed by the spherical surface as the design value which shows r4 which is not shown in Table 3, r7, r8, r16, r18, r20, r24, r25, r26-r30, r32, r33, r36, r38-r44, and the page [27th] lens side of r53-r56 in Table 1.

[0075] In Table 3, in addition, the aspheric surface configuration of the measured lens side The height from an optical axis is set to h, and the distance in alignment with the optical axis from the point on the aspheric surface in height h from an optical axis to the tangential plane in lens top-most vertices is expressed like the above-mentioned (7) types, when setting r and a cone constant to k and setting [the radius of curvature of X (h) and paraxial] i and a 2i order aspheric surface multiplier to C2i for the natural number.

X (h) [1+(1-kA/r) 0.5]+C2 h2+C4 h4+ They are +C2ih2i, however A=h2 / r.

[0076] In addition, when this aspheric surface type (or (7) types) is expressed by above-mentioned (8) formulas, it becomes the case where all (C1, C3, C5, C7, C9, C9, C11, C13, C15) of the oddth aspheric surface multiplier are made into zero.

[0077]

[Table 3]

r1(body side face of lens L11) k=1C2 = -5.471x10-9 C4 = 7.211x10-12 C6 = -6.987x10-15, C8 = 3.581x10-18 C10=-9.940x10-22, C12= 1.515x10-25 C14=-1.189x10-29, C16= 3.746x10-34
 r2(image side face of lens L11) k=1C2 = 9.640x10-9 C4 = -1.559x10-11 C6 = 7.989x10-15, C8 = -1.994x10-18 C10= 2.676x10-22, C12=-1.970x10-26 C14= 7.842x10-31, C16=-1.486x10-35
 r3(body side face of lens L12) k=1C2 = 2.504x10-9, C4 = 1.800x10-12 C6 = -1.945x10-15, C8 = 7.684x10-19 C10=-1.617x10-22, C12= 1.883x10-26C14=-1.140x10-30, C16= 2.796x10-35
 r5(body side face of lens L13) k=1C2 = -9.776x10-9 C4 = 1.584x10-11 C6 = -7.836x10-15, C8 = 1.971x10-18 C10=-2.706x10-22, C12= 1.945x10-26 C14=-6.176x10-31, C16= 3.939x10-36
 r6(image side face of lens L13) k=1C2 = -1.281x10-8 C4 = 6.967x10-12 C6 = -1.619x10-15, C8 = 2.539x10-19 C10=-4.180x10-23, C12= 5.733x10-27C14=-4.365x10-31, C16= 1.315x10-35
 r9(body side face of lens L2F) k=1C2 = -8.091x10-9 C4 = 1.051x10-11 C6 = -1.073x10-14, C8 = 5.072x10-18 C10=-1.232x10-21, C12= 1.619x10-25C14=-1.097x10-29, C16= 3.005x10-34
 r10(image side face of lens L2F) k=1C2 = 1.208x10-8, C4 = -3.713x10-12 C6 = 1.231x10-15 and C8 =-3.068x10-18 C10= 2.347x10-21, C12=-7.694x10-25 C14= 1.169x10-28, C16=-6.760x10-33 r11(body side face of lens LM1) k=1C2 = -3.296x10-8 C4 = 6.279x10-11 C6 =-5.572x10-14, C8 = 3.563x10-17 C10=-1.492x10-20, C12=

$3.643 \times 10^{-24} C_{14} = -4.659 \times 10^{-28}$, $C_{16} = 2.397 \times 10^{-32} r_{12}$ (image side face of lens LM1) $k=1 C_2 = 2.002 \times 10^{-8}$, $C_4 = -3.252 \times 10^{-11}$ $C_6 = 2.300 \times 10^{-14}$, $C_8 = -2.545 \times 10^{-18}$ $C_{10} = -6.506 \times 10^{-21}$, $C_{12} = 3.926 \times 10^{-24}$ $C_{14} = -8.762 \times 10^{-28}$, $C_{16} = 6.968 \times 10^{-32} r_{13}$ (body side face of lens LM2) $k=1 C_2 = 5.766 \times 10^{-9}$ and $C_4 = -4.636 \times 10^{-11}$ $C_6 = 6.549 \times 10^{-14}$ and $C_8 = -4.629 \times 10^{-17}$ $C_{14} = 5.396 \times 10^{-28}$ and $C_{16} = -2.777 \times 10^{-32} r_{14}$ (image side face of lens LM2) $k=1 C_2 = 4.539 \times 10^{-8}$ $C_4 = -7.979 \times 10^{-11}$ $C_6 = 7.887 \times 10^{-14}$ and $C_8 = -5.989 \times 10^{-17}$ $C_{10} = 4.596 \times 10^{-20}$, $C_{12} = -2.583 \times 10^{-23}$ $C_{14} = 7.533 \times 10^{-27}$, $C_{16} = -8.407 \times 10^{-31} r_{15}$ (body side face of lens LM3) $k=1 C_2 = -3.853 \times 10^{-8}$ $C_4 = 6.880 \times 10^{-11}$ $C_6 = -9.409 \times 10^{-14}$, $C_8 = 8.629 \times 10^{-17}$ $C_{10} = -5.002 \times 10^{-20}$, $C_{12} = 1.716 \times 10^{-23}$ $C_{14} = -3.068 \times 10^{-27}$, $C_{16} = 2.139 \times 10^{-31} r_{17}$ (body side face of lens LM4) $k=1 C_2 = -3.484 \times 10^{-8}$ $C_4 = 4.891 \times 10^{-11}$ $C_6 = -6.547 \times 10^{-14}$, $C_8 = 5.864 \times 10^{-17}$ $C_{10} = -3.072 \times 10^{-20}$, $C_{12} = 8.969 \times 10^{-24}$ $C_{14} = -1.308 \times 10^{-27}$, $C_{16} = 7.039 \times 10^{-32} r_{19}$ (body side face of lens LM5) $k=1 C_2 = 9.291 \times 10^{-9}$ $C_4 = 1.762 \times 10^{-12}$ $C_6 = -5.641 \times 10^{-15}$, $C_8 = 3.610 \times 10^{-18}$ $C_{10} = -1.147 \times 10^{-21}$, $C_{12} = 1.958 \times 10^{-25}$ $C_{14} = -1.716 \times 10^{-29}$, $C_{16} = 6.070 \times 10^{-34} r_{21}$ (body side face of lens L2R) $k=1 C_2 = -1.793 \times 10^{-9}$ $C_4 = 8.806 \times 10^{-12}$ $C_6 = -1.134 \times 10^{-14}$, $C_8 = 6.366 \times 10^{-18}$ $C_{10} = -1.936 \times 10^{-21}$, $C_{12} = 3.284 \times 10^{-25}$ $C_{14} = -2.890 \times 10^{-29}$, $C_{16} = 1.022 \times 10^{-33} r_{22}$ (image side face of lens L2R) $k=1 C_2 = 2.095 \times 10^{-8}$ $C_4 = -2.339 \times 10^{-11}$ $C_6 = 1.406 \times 10^{-14}$, $C_8 = -4.552 \times 10^{-18}$ $C_{10} = 8.283 \times 10^{-22}$ and $C_{12} = -8.499 \times 10^{-26}$ $C_{14} = 4.593 \times 10^{-30}$, $C_{16} = -1.017 \times 10^{-34} r_{23}$ (body side face of lens L31) $k=1 C_2 = -3.700 \times 10^{-9}$ $C_4 = 1.870 \times 10^{-12}$ $C_6 = -5.376 \times 10^{-16}$, $C_8 = 3.559 \times 10^{-20}$ $C_{10} = 1.000 \times 10^{-23}$, $C_{12} = -2.129 \times 10^{-27}$ $C_{14} = 1.566 \times 10^{-31}$, $C_{16} = -4.112 \times 10^{-36} r_{31}$ (body side face of lens L41) $k=1 C_2 = -1.652 \times 10^{-8}$ $C_4 = 2.774 \times 10^{-12}$ $C_6 = 4.818 \times 10^{-15}$, $C_8 = -3.252 \times 10^{-18}$ $C_{10} = 9.372 \times 10^{-22}$, $C_{12} = -1.430 \times 10^{-25}$ $C_{14} = 1.124 \times 10^{-29}$, $C_{16} = -3.585 \times 10^{-34} r_{34}$ (image side face of lens L42) $k=1 C_2 = -1.756 \times 10^{-8}$, $C_4 = 1.631 \times 10^{-11}$ $C_6 = -7.091 \times 10^{-15}$, $C_8 = 1.179 \times 10^{-19}$ $C_{10} = 1.068 \times 10^{-21}$, $C_{12} = -3.875 \times 10^{-25}$ $C_{14} = 5.632 \times 10^{-29}$, $C_{16} = -3.048 \times 10^{-33} r_{35}$ (body side face of lens L43) $k=1 C_2 = -3.427 \times 10^{-8}$ $C_4 = 5.336 \times 10^{-11}$ $C_6 = -3.932 \times 10^{-14}$, $C_8 = 1.308 \times 10^{-17}$ $C_{10} = -1.146 \times 10^{-21}$, $C_{12} = -4.070 \times 10^{-25}$ $C_{14} = 1.117 \times 10^{-28}$, $C_{16} = -8.291 \times 10^{-33} r_{37}$ (body side face of lens L44) $k=1 C_2 = 4.750 \times 10^{-8}$ and $C_4 = -2.692 \times 10^{-12}$ $C_6 = -1.583 \times 10^{-14}$, $C_8 = 2.256 \times 10^{-17}$ $C_{10} = -1.298 \times 10^{-20}$, $C_{12} = 3.758 \times 10^{-24}$ $C_{14} = -5.379 \times 10^{-28}$, $C_{16} = 3.020 \times 10^{-32} r_{45}$ (body side face of lens L54) $k=1 C_2 = -1.581 \times 10^{-9}$ $C_4 = -7.300 \times 10^{-12}$ $C_6 = 3.438 \times 10^{-15}$, $C_8 = -6.407 \times 10^{-19}$ $C_{10} = 4.045 \times 10^{-23}$, $C_{12} = 2.557 \times 10^{-27}$ $C_{14} = -4.391 \times 10^{-31}$, $C_{16} = 1.501 \times 10^{-35} r_{46}$ (image side face of lens L54) $k=1 C_{12} = -2.319 \times 10^{-8}$ $C_4 = 2.142 \times 10^{-11}$ $C_6 = -9.743 \times 10^{-15}$, $C_8 = 2.355 \times 10^{-18}$ $C_{10} = -3.234 \times 10^{-22}$, $C_{12} = 2.546 \times 10^{-27}$ $C_{14} = -1.073 \times 10^{-30}$, $C_{16} = 1.877 \times 10^{-35} r_{47}$ (body side face of lens L55) $k=1 C_2 = 7.534 \times 10^{-9}$ $C_4 = -1.324 \times 10^{-12}$ $C_6 = 1.738 \times 10^{-16}$, $C_8 = 1.051 \times 10^{-19}$ $C_{10} = -4.377 \times 10^{-23}$, $C_{12} = 6.217 \times 10^{-27}$ $C_{14} = -3.932 \times 10^{-31}$, $C_{16} = 9.384 \times 10^{-36} r_{49}$ (body side face of lens L56) $k=1 C_2 = -8.499 \times 10^{-9}$ $C_4 = 4.471 \times 10^{-12}$ $C_6 = -2.412 \times 10^{-15}$, $C_8 = 1.080 \times 10^{-18}$ $C_{10} = -2.747 \times 10^{-22}$, $C_{12} = 3.709 \times 10^{-26}$ $C_{14} = -2.503 \times 10^{-30}$, $C_{16} = 6.654 \times 10^{-35} r_{50}$ (image side face of lens L56) $k=1 C_2 = -8.992 \times 10^{-11}$, $C_4 = 4.380 \times 10^{-12}$ $C_6 = -3.536 \times 10^{-15}$, $C_8 = 1.459 \times 10^{-18}$ $C_{10} = -3.388 \times 10^{-22}$, $C_{12} = 4.466 \times 10^{-26}$ $C_{14} = -3.120 \times 10^{-30}$, $C_{16} = 8.912 \times 10^{-35} r_{51}$ (body side face of lens L57) $k=1 C_2 = -2.893 \times 10^{-8}$ $C_4 = -1.291 \times 10^{-14}$ $C_6 = 1.271 \times 10^{-14}$, $C_8 = -7.075 \times 10^{-18}$ $C_{10} = 1.863 \times 10^{-21}$, $C_{12} = -2.673 \times 10^{-25}$ $C_{14} = 2.008 \times 10^{-29}$, $C_{16} = -6.190 \times 10^{-34} r_{52}$ (image side face of lens L57) $k=1 C_2 = 1.227 \times 10^{-8}$ $C_4 = -1.288 \times 10^{-11}$ $C_6 = 1.178 \times 10^{-14}$, $C_8 = -5.922 \times 10^{-18}$ $C_{10} = 1.623 \times 10^{-21}$, $C_{12} = -2.449 \times 10^{-25}$ $C_{14} = 1.915 \times 10^{-29}$, $C_{16} = -6.065 \times 10^{-34} r_{54}$ (image side face of lens L58) $k=1 C_2 = 4.194 \times 10^{-8}$ and $C_4 = -1.060 \times 10^{-10}$ $C_6 = 2.183 \times 10^{-13}$, $C_8 = -2.482 \times 10^{-16}$ $C_{10} = 1.558 \times 10^{-19}$, $C_{12} = -5.406 \times 10^{-23}$ $C_{14} = 9.678 \times 10^{-27}$ and $C_{16} = -6.960 \times 10^{-31}$ At [step 3], next step 3 A maintenance unit is assembled so that each lens with which the lens side was measured at step 2 may be held at a maintenance frame, respectively, and projection optics PL is assembled, dropping each assembled maintenance unit into a lens-barrel in predetermined sequence, as shown in drawing 4 or drawing 5. More by the way, this assembler sets, considering the thickness of the washer (3A-3E, 5A-5D) contain in a lens-barrel with a maintenance unit in the information about spacing of the optical surface (lens side) of each lens, it measures using tools (micrometer etc.) and the memory section of the operation systems 7, such as a computer and a computer, is make to memorize the measured result through the input

systems 6, such as a console.

[Step 4] In step 4, the aberration of the projection optics PL immediately after assembling at step 3 was measured using the test mask shown in drawing 7 and drawing 8, and as the image surface gryposis shows then the curve a of drawing 9, it is generated.

[Step 5] For this reason, at step 5, the optical master data beforehand memorized by the operation systems 7, such as a computer and a computer, at memory circles based on two information (information about spacing of the lens side of each lens obtained like the information (optical data shown in Table 3) about a field configuration and the assembler of each lens) memorized by memory circles corrects in advance of adjustment of projection optics PL. And the operation system 7 computes the amount of spacing amendments of the lens side of each lens which aberration can amend based on the information on the corrected optical master data, and the information about the amount of aberration about many aberration which remains in projection optics PL, and expresses information, such as the amount of spacing amendments of the lens side of each lens, as the display systems 8, such as a non-illustrated CRT monitor.

[0078] The adjustment technique of making a lens relative spacing in the direction of an optical axis between lenses incline to change or an optical axis based on the amount of spacing amendments of the lens side of each of this displayed lens by exchange of the washer inside projection optics PL used as the subject of examination shown in drawing 4 or drawing 5 (3A-3E, 5A-5D) etc. is performed. Adjustment of projection optics PL is made by this, and the image surface gryposis of a low degree [****] shown in each curve a of drawing 9 is removed. It is parallel to this adjustment process, and the memory section of the operation systems 7, such as a computer and a computer, is made to memorize the information on spacing of the lens side (optical surface) of each called-for lens of projection optics PL through the input systems 6, such as a console.

[Step 6] At step 6, after the image surface gryposis of a low degree is removed by adjustment of projection optics PL, the high order aberration which remains in projection optics PL is measured.

[0079] The measurement at this time detects the high order image surface gryposis of the projection optics PL to be examined using the test mask TR1 like step 2. In the case of this example, as are shown in the curve b of drawing 9, and the high order image surface gryposis is shown in drawing 13, it has generated. In addition, in order to simplify explanation in this example, spacing of the optical surface (lens side) of each lens of the projection optics PL in the phase which the adjustment process completed shall have become as a design value, as shown in the lens data of Table 1.

[0080] The memory section of the operation systems 7, such as a computer and a computer, is made to memorize the information about the high order amount of aberration which remains in the measured projection optics PL through the input systems 6, such as a console, in the high order aberration measurement process of this step 6, as shown in drawing 3.

[Step 7]

[1st substep] It precedes in quest of the aspheric surface which should amend the high order image surface gryposis. First the operation systems 7, such as a computer The information about spacing of the optical surface (lens side) of each lens of the projection optics PL after adjustment process completion of step 5 is used. Information about the manufacture optical data of the projection optics PL acquired in advance of the adjustment process of step 5 (it is based on the information about spacing of the lens side of each lens obtained like the assembler of the information about the field configuration of the lens side of each lens obtained at step 2, and step 3 etc.) The information on the optical data in the time of setting up of the corrected projection optics PL is re-corrected, and the optical data in the manufacture process of the projection optics PL after adjustment process completion of step 5 are reproduced.

[0081] Here, in order to simplify explanation in this example, spacing of the optical surface (lens side) of each lens of the projection optics PL in the phase which the adjustment process completed shall have become as a design value, as shown in the lens data of Table 1. For this reason, the operation systems 7, such as a computer, season the data of the projection optics

PL shown in Table 1 with the data of the aspheric surface shown in Table 3, and update lens data (correction).

[0082] The situation of the image surface gryposis when seasoning the data of the projection optics PL shown in Table 1 with the data of the aspheric surface shown in Table 3, and updating lens data (correction) is shown in drawing 13. As compared with the curve b of the image surface gryposis of drawing 9 actually measured at step 6, the curve of the image surface gryposis shown in drawing 13 shows the aberration value almost same in each image quantity, and can understand that the optical data in the manufacture process of the projection optics PL after adjustment process completion of step 5 are reproduced.

[0083] Next, it is based on the information about the amount of aberration about many high order aberration which remains in the projection optics PL acquired at step 6 as information memorized by the manufacture optical data at the time of the reproduced completion of adjustment like ****, and memory circles (based on the data shown in Table 1 and 3 by this example). The operation systems 7, such as a computer, perform ray tracing, and determine the minute aspheric surface which can amend the high order image surface gryposis which remains in projection optics PL. At this time, it is the 2nd lens group G2 at this example. Negative lens M2 in an intermediary group GM 1 The example which designed the minute aspheric surface which can amend the high order image surface gryposis which remains in projection optics PL to the lens side (the 13th lens side) of the concave configuration by the side of a body is shown.

[0084] Here, it is the 2nd lens group G2. Negative lens M2 in an intermediary group GM 1 The data of the aspheric surface which should be established in a body side face (the 13th lens side) are hung up over Table 4. In addition, the correspondence value of the above-mentioned (1) type - (5) type is collectively shown in Table 4.

[0085]

[Table 4]

$r_{13}(\text{body side face of negative lens M2})$ $k=1C2 = 0.502 \times 10 - 7C4 = -0.687 \times 10 - 10C6 = 0.717 \times 10 - 13C8 = -0.605 \times 10 - 16C10 = 0.308 \times 10 - 19C12 = -0.870 \times 10 - 23C14 = 0.128 \times 10 - 26C16 = -0.767 \times 10 - 31S = 0.021 \text{micromS}(n-1)/\lambda = 0.0430C = 0.00099 (1/\text{mm})$

The $d/D=0.1802$ 2nd lens group G2 Negative lens M2 in an intermediary group GM 1 As shown in drawing 1414, the aspheric surface which should be established in the concave surface by the side of a body (the 13th lens side) has the aspheric surface configuration with two point of inflection from an optical axis before the maximum image quantity (the maximum effective diameter), and has four point of inflection as the whole lens side surface. Thus, on the whole aspheric surface surface, it becomes it is desirable and possible [that this amends high order aberration with sufficient balance] to consider as a configuration with four or more point of inflection. In addition, the amount of displacement of an aspheric surface configuration is shown on an axis of ordinate by drawing 14, and the height from the optical axis of a lens side is shown on the axis of abscissa.

[the 2nd substep] -- now, the **** minute aspheric surface shown in Table 4 called for by ray tracing using the operation systems 7, such as a computer, -- negative lens M2 in projection optics PL In order to form in the concave surface by the side of a body (the 13th lens side), the one section or all of projection optics PL is decomposed if needed, and the optical unit which should perform aspheric surface processing is taken out. Then, after the lens in an optical unit takes out, it is a negative lens M2. The **** lens polish processing machine which showed aspheric surface processing to drawing 11 to the concave surface (the 13th lens side) by the side of a body performs.

[3rd substep] A maintenance frame is attached after an antireflection film will be given according to the negative lens M2 with which processing was performed, a vacuum evaporationo process, etc., if processing by the lens polish processing machine of the above drawing 11 was completed. And the optical unit which finally holds the lens by which aspheric surface processing was carried out with the lens polish processing machine is included in projection optics PL.

[0086] And the image surface gryposis in the phase incorporated and completed is shown in drawing 15. As shown in drawing 15, the image surface gryposis of the **** high order shown

in Curve b and drawing 13 of drawing 9 is removed, and he can understand that manufacture of the projection optics PL with the outstanding image formation engine performance is attained. It is the 2nd lens group G2 about the aspheric surface which amends the high order image surface gryposis above. Negative lens M2 in an intermediary group GM 1 Although the example prepared in the body side face was shown next, the 2nd example which established the aspheric surface which amends high order distortion aberration (distortion) is explained. In addition, in order to simplify explanation, let the error aspheric surface of each lens which constitutes the projection optics shown in the basic lens data and Table 3 showing in the above-mentioned table 1 be the same thing also in the 2nd example. Therefore, since step 1 as a process which manufactures the lens-barrel which contains the maintenance unit which becomes each lens list which constitutes the projection optics PL with which the lens data shown in Table 1 fill from the maintenance frame and the lens holding each lens, and a maintenance frame, step 2 as a process which measures a configuration for the lens side of the lens manufactured at step 1, and step 3 as a process which assembles projection optics PL are the same, explanation omits.

[Step 4] After passing through the process of the above step 1 – step 3, in step 4, the aberration of the projection optics PL immediately after assembling at step 3 was measured using the test mask shown in drawing 7 and drawing 8 , and as distortion aberration (distortion) shows then the curve a of drawing 10 , it is generated.

[Step 5] For this reason, adjustment of projection optics PL is preceded at step 5. By the operation systems 7, such as a computer and a computer Based on two information (information about spacing of the lens side of each lens obtained like the information (optical data shown in Table 3) about a field configuration and the assembler of a lens side in each lens) memorized by memory circles, the optical master data beforehand memorized by memory circles is corrected. And the operation system 7 computes the amount of spacing amendments of the lens side (optical surface) of each lens which can amend aberration based on the information on the corrected optical master data, and the information about the amount of aberration about many aberration which remains in projection optics PL, and expresses information, such as the amount of spacing amendments of the lens side (optical surface) of each lens, as the display systems 8, such as a non-illustrated CRT monitor.

[0087] The adjustment technique of making a lens relative spacing in the direction of an optical axis between lenses incline to change or an optical axis based on the amount of spacing amendments of the lens side of each of this displayed lens by exchange of the washer inside projection optics PL used as the subject of examination shown in drawing 4 or drawing 5 (3A-3E, 5A-5D) etc. is performed. The distortion aberration of a low degree [****] which adjustment is made and shows projection optics PL by this to each curve a of drawing 10 is removed. It is parallel to this adjustment process, and the memory section of the operation systems 7, such as a computer and a computer, is made to memorize the information on spacing of the optical surface (lens side) of each called-for lens of projection optics PL through the input systems 6, such as a console.

[Step 6] At step 6, after the distortion aberration of a low degree is removed by adjustment of projection optics PL, the high order distortion aberration which remains in projection optics PL is measured.

[0088] The measurement at this time detects the high order distortion aberration of the projection optics PL to be examined using the test mask TR2 like step 2. In the case of this example, as are shown in the curve b of drawing 10 , and the high order image surface gryposis is shown in drawing 16 , it has generated. In addition, in order to simplify explanation in this example, spacing of the optical surface (lens side) of each lens of the projection optics PL in the phase which the adjustment process completed shall have become as a design value, as shown in the lens data of Table 1.

[0089] The memory section of the operation systems 7, such as a computer and a computer, is made to memorize the information about the high order amount of aberration which remains in the measured projection optics PL through the input systems 6, such as a console, in the high order aberration measurement process of this step 6, as shown in drawing 3 .

[Step 7]

[1st substep] It precedes in quest of the aspheric surface which should amend high order distortion aberration. First the operation systems 7, such as a computer The information about spacing of the optical surface (lens side) of each lens of the projection optics PL after adjustment process completion of step 5 is used. Information about the manufacture optical data of the projection optics PL acquired in advance of the adjustment process of step 5 (it is based on the information about spacing of the optical surface of each lens obtained like the assembler of the information about the field configuration of each lens obtained at step 2, and step 3 etc.) The information on the optical data in the time of setting up of the corrected projection optics PL is re-corrected, and the optical data in the manufacture process of the projection optics PL after adjustment process completion of step 5 are reproduced.

[0090] Here, 1st similarly [in the 2nd example / above-mentioned], in order to simplify explanation, spacing of the optical surface (lens side) of each lens of the projection optics PL in the phase which the adjustment process completed shall have become as a design value, as shown in the lens data of Table 1. For this reason, the operation systems 7, such as a computer, season the data of the projection optics PL shown in Table 1 with the data of the aspheric surface shown in Table 3, and update lens data (correction).

[0091] The situation of the distortion aberration when seasoning the data of the projection optics PL shown in Table 1 with the data of the aspheric surface shown in Table 3, and updating lens data (correction) is shown in drawing 16 . as compared with the curve b of the distortion aberration of drawing 9 by which the curve of the distortion aberration shown in drawing 16 was actually measured at step 6, the aberration value almost same in each image quantity is shown, and the optical data in the manufacture process of the projection optics PL after adjustment process completion of step 5 are reproduced -- he can understand.

[0092] Next, it is based on the information about the amount of aberration about many high order aberration which remains in the projection optics PL acquired at step 6 as information memorized by the manufacture optical data at the time of the reproduced completion of adjustment like ****, and memory circles (based on the data shown in Table 1 and 3 by this example). The operation systems 7, such as a computer, perform ray tracing, and determine the minute aspheric surface which can amend the high order distortion aberration which remains in projection optics PL. At this time, it is the 1st lens group G1 at this example. The example which designed the minute aspheric surface which can amend the high order distortion aberration which remains in projection optics PL to the lens side (the 1st lens side) of the convex configuration by the side of the body of a positive lens L11 is shown.

[0093] Here, it is the 1st lens group G1. The data of the aspheric surface which should be established in the lens side by the side of the body of a positive lens L11 (the 1st lens side) are hung up over Table 5. In addition, the correspondence value of the above-mentioned (1) type - (5) type is collectively shown in Table 5.

[0094]

[Table 5]

$r1(\text{body side face of positive lens L11}) k=1C2 = 0.502 \times 10^{-7} C4 = -0.392 \times 10^{-10} C6 = 0.162 \times 10^{-13} C8 = -0.471 \times 10^{-17} C10 = 0.921 \times 10^{-21} C12 = -0.109 \times 10^{-24} C14 = 0.696 \times 10^{-29} C16 = -0.183 \times 10^{-33} S = 0.024 \text{micromS} (n-1) / \lambda = 0.049 C = 0.00138 (1/\text{mm})$

The $d/D=0$ 1st lens group G1 As shown in drawing 17 , the aspheric surface which should be established in the lens side (the 1st lens side) of the convex configuration by the side of the body of a positive lens L11 has the aspheric surface configuration with two point of inflection from an optical axis before the maximum image quantity (the maximum effective diameter), and has four point of inflection as the whole lens side surface. Thus, on the whole aspheric surface surface, it becomes it is desirable and possible [that this amends high order aberration with sufficient balance] to consider as a configuration with four or more point of inflection. In addition, the amount of displacement of an aspheric surface configuration is shown on an axis of ordinate by drawing 17 , and the height from the optical axis of a lens side is shown on the axis of abscissa.

[the 2nd substep] -- now, the **** minute aspheric surface shown in Table 4 called for by ray tracing using the operation systems 7, such as a computer, -- the 1st lens group G1 in projection optics PL In order to form in the body side face of a positive lens L11, the one section or all of projection optics PL is decomposed if needed, and the optical unit which should perform aspheric surface processing is taken out. Then, after the lens in an optical unit takes out, the **** lens polish processing machine which showed aspheric surface processing to drawing 11 to the lens side (the 1st lens side) by the side of the body of a positive lens L11 performs.

[3rd substep] If processing by the lens polish processing machine of the above drawing 11 is completed, as for the positive lens L11 with which processing was performed, a maintenance frame will be attached after an antireflection film is given according to a vacuum evaporation process etc. And the optical unit which finally holds the lens by which aspheric surface processing was carried out with the lens polish processing machine is included in projection optics PL.

[0095] And the distortion aberration in the phase incorporated and completed is shown in drawing 18 . As shown in drawing 18 , the distortion aberration of a **** high order shown in Curve b and drawing 16 of drawing 10 is removed, and he can understand that manufacture of the projection optics PL with the outstanding image formation engine performance is attained. Although each above example showed the aspheric surface which amends the image surface gryposis and distortion aberration independently, respectively, the 1st [at least / or more] page of the aspheric surface which amends to coincidence each aberration which remains in projection optics may be formed. Moreover, a curvature of field and not only distortion aberration but the aspheric surface by this invention can amend image formation properties, such as aberration, such as comatic aberration, spherical aberration, and astigmatism, and tele cent rucksack nature, etc. Furthermore, it is also possible to amend two or more of such aberration etc. to coincidence.

[0096] Furthermore, although each above example showed the example in which the aspheric surface was formed to the lens side of a lens with refractive power, in this invention, the aspheric surface which amends the high order aberration which remains in projection optics in the flat-surface [of a plano-convex lens] or flat-surface side (field where refractive power serves as zero) (field where refractive power serves as zero) of a plano-concave lens may be formed. Furthermore, in this invention, when projection optics is constituted from optical system of a reflective refraction mold, the aspheric surface which amends the high order aberration which remains in projection optics may be formed in at least one reflector at the time of constituting projection optics from catoptric system.

[0097] Moreover, it may constitute possible [insertion and detachment of the plane-parallel plate of light transmission nature with which refractive power serves as zero between projection optics and a mask or between projection optics and a photosensitive substrate (wafer)], and the aspheric surface which amends the high order aberration which remains in projection optics may be formed in the front face of the plane-parallel plate. In this case, although it will pass through the process same from step 1 stated above to step 8, attachment of the plane-parallel plate to projection optics is very easy for the ejection list of the plane-parallel plate from projection optics. Consequently, in order to attach the optical element to which the coat of aspheric surface processing and an antireflection film was given in the activity and the 3rd substep which decompose the one section or all of projection optics PL if needed in order to take out the optical element for performing aspheric surface processing at the 2nd substep in carrying out aspheric surface processing of the plane-parallel plate, projection optics PL is assembled again, the activity which adjusts can be done unnecessary and working efficiency can be raised.

[0098] in addition, not only a component with the aspheric surface symmetrical with rotation of aberration by this invention which amends the aberration which remains in projection optics but rotation -- it cannot be overemphasized that an unsymmetrical aberration component is removable. for this reason, the aspheric surface by this invention -- an optical axis -- receiving -- rotation -- it is clear that it is good also as an unsymmetrical configuration. Moreover,

although each above example showed the example which established the aspheric surface which amends the high order aberration which remains in the projection optics which carries out contraction projection of the mask pattern at a photosensitive substrate, the aspheric surface which amends the high order aberration which remains in the projection optics which projects not only this but a mask pattern on a photosensitive substrate by actual size or expansion may be established.

[0099] In each example shown above, even if the process tolerance of the optic which constitutes projection optics is loose, as a result of finishing setting up, since a high order aberration component will be removed and it will have high optical-character ability, according to the projection optics as an object, the percent defective of the optic itself is reduced and there is an advantage which can manufacture projection optics efficiently. Moreover, if the process tolerance of an optic is comparable as former, there is an advantage which can attain higher optical-character ability than former.

[0100]

[Effect of the Invention] Manufacture with the sufficient effectiveness of projection optics with the high optical-character ability from which the high order aberration component was removed can be enabled without inviting like the above the defect of the optic which constitutes projection optics, and the own defect of projection optics according to this invention. For this reason, in this invention, the manufacture approach of various kinds of components including the manufacture approach of the projection optics which a high order aberration component can remove, the projection aligner which can carry out projection exposure of the more detailed mask pattern good to a photosensitive substrate, and a semiconductor device with a further more high degree of integration is realizable.

[Translation done.]

*** NOTICES ***

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1. This document has been translated by computer. So the translation may not reflect the original precisely.
2. **** shows the word which can not be translated.
3. In the drawings, any words are not translated.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1] Drawing 1 is drawing for [in which the projection aligner by this invention carries out an outline configuration] explaining.

[Drawing 2] Drawing 2 is drawing for explaining the manufacture process of the projection optics by this invention.

[Drawing 3] Drawing 3 is drawing showing the process for reproducing the optical data of the manufacture process of the projection optics by this invention.

[Drawing 4] It is drawing showing the situation of the maintenance structure of the projection optics shown in drawing 1 .

[Drawing 5] It is drawing showing another structure with the maintenance structure of the projection optics shown in drawing 4 .

[Drawing 6] It is drawing showing the configuration of the Fizeau mold interferometer which measures the configuration of the optical surface of the optical element which constitutes projection optics.

[Drawing 7] It is drawing showing the appearance of the test mask for measuring the image surface gryposis which remains in projection optics.

[Drawing 8] It is drawing showing the appearance of the test mask for measuring the distortion aberration which remains in projection optics.

[Drawing 9] It is drawing showing the situation of the image surface gryposis which remains in projection optics.

[Drawing 10] It is drawing showing the situation of the distortion aberration which remains in projection optics.

[Drawing 11] It is drawing showing the configuration of the aspheric surface processing machine which forms in an optical surface the aspheric surface which amends many high order aberration which remains in projection optics.

[Drawing 12] It is the lens block diagram of the projection optics concerning the example of this invention.

[Drawing 13] It is drawing showing signs that the high order image surface gryposis remains in the projection optics shown in drawing 12 .

[Drawing 14] It is drawing showing the situation of the aspheric surface configuration for amending the high order image surface gryposis shown in drawing 13 .

[Drawing 15] It is drawing showing signs that the high order image surface gryposis is amended by the aspheric surface configuration shown in drawing 14 .

[Drawing 16] It is drawing showing signs that high order distortion aberration remains in the projection optics shown in drawing 12 .

[Drawing 17] It is drawing showing the situation of the aspheric surface configuration for amending the high order distortion aberration shown in drawing 16 .

[Drawing 18] It is drawing showing signs that high order distortion aberration is amended by the aspheric surface configuration shown in drawing 17 .

[Drawing 19] It is drawing showing the rough configuration of a scanning projection aligner.
[Description of Notations]

R Mask
W Wafer
PL Projection optics
1, 4A-4E Lens-barrel
2A-2E Maintenance frame
3A-3E, 5A-5D Washer
L1 -L5 Lens
G1 The 1st lens
G2 The 2nd lens
G3 The 3rd lens
G4 The 4th lens
G5 The 5th lens
G6 The 6th lens

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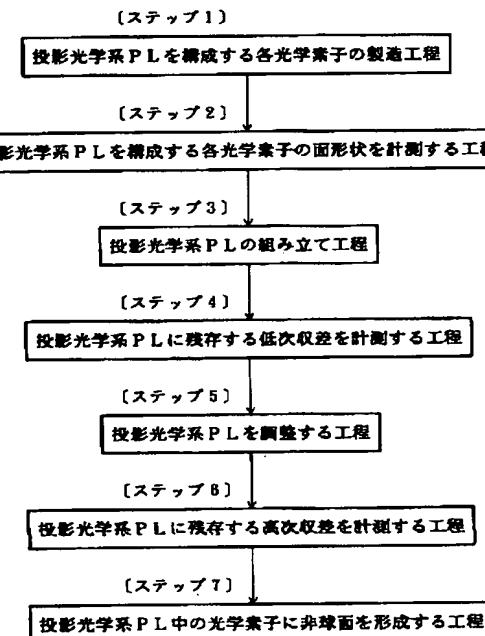
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(54)【発明の名称】 投影光学系の製造方法、投影露光装置および半導体装置の製造方法

(57)【要約】

【課題】高次の収差成分が除去し得る投影光学系の製造方法、マスクパターンを感光性基板に良好に投影露光し得る投影露光装置、さらにはより高い集積度を持つ半導体素子を始めとした各種の素子の製造方法の提供にある。

【解決手段】複数の光学部材を用いて投影光学系を組み立てるに先立って計測された複数の光学部材の光学面の形状に関する情報と、その複数の光学部材を用いて投影光学系を組み立て中または組み立て後に前記複数の光学部材の配置に関する情報を用いて、投影光学系に残存する収差を除去する非球面を前記複数の光学部材に形成する。



【特許請求の範囲】

【請求項1】第1物体の像を第2物体上へ投影するための投影光学系の製造方法において、前記投影光学系を構成すべき複数の光学部材を製造する第1工程と、該第1工程によって製造された複数の光学部材の光学面の面形状をそれぞれ計測する第2工程と、前記第1工程にて製造された前記複数の光学部材を用いて投影光学系を組み立てる第3工程と、該第3工程後にて前記投影光学系に残存する収差を計測するための第4工程と、該第4工程によって計測された収差を補正するために前記投影光学系を調整すると共に、該調整中又は調整完了時の前記投影光学系を構成する前記複数の光学部材間の光学面の間隔を求める第5工程と、前記第5工程後にて前記投影光学系に残存する高次の収差を計測する第6工程と、前記第2工程にて得られた各光学部材の面形状の情報と、前記第5工程にて得られた前記複数の光学部材間の光学面の間隔の情報と、前記投影光学系の光学設計情報とに基づいて、前記第6工程にて得られた残存する高次収差量を補正する非球面を前記複数の光学部材の少なくとも1つに形成する第7工程とを有することを特徴とする投影光学系の製造方法。

【請求項2】前記第7工程にて形成される前記非球面は、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、
 $0.02 < S(n-1)/\lambda < 0.483$

を満足することを特徴とする請求項1記載の投影光学系の製造方法。

【請求項3】前記非球面を前記光学部材の屈折面に形成し、該屈折面の曲率をCとするとき、
 $|C| < 0.02$

を満足することを特徴とする請求項1または請求項2に記載の投影光学系の製造方法。

【請求項4】前記投影光学系の最も第1物体側の光学部材の屈折面から前記投影光学系の最も第2物体側の光学部材の屈折面までの光軸に沿った長さをDとし、前記投影光学系の最も第1物体側の光学部材の屈折面から前記非球面が形成される光学部材の屈折面までの光軸に沿った距離をdとするとき、
 $0 \leq d/D < 0.37$

の条件を満足することを特徴とする請求項1から請求項3のいずれかに記載の投影光学系の製造方法。

【請求項5】前記非球面は、光軸からの高さをhとし、光軸からの高さhにおける非球面上の点からレンズ頂点での接平面までの光軸に沿った距離をX(h)、近軸の曲率半径をr、円錐定数をk、少なくとも1から12までの自然数をn、n次の非球面係数をCnとするとき、

以下の式を満足する特徴とする請求項1から請求項4のいずれかに記載の投影光学系の製造方法。

$$X(h) = A / [1 + (1 - kA/r)^{0.5}] + C_1 h^1 + C_2 h^2 + C_3 h^3 + C_4 h^4 + \dots + C_n h^n$$

但し、 $A = h^2 / r$ である。

【請求項6】照明光学系からの露光光をマスク上に形成されたパターンに照明し、該パターンを投影光学系を介して感光性基板に露光する投影露光装置において、前記投影光学系は、前記パターンの像を前記感光性基板に形成するための複数の光学部材を有し、前記投影光学系に残存する収差成分を補正するための非球面を前記複数の光学部材の少なくとも1つに形成し、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、
 $0.02 < S(n-1)/\lambda < 0.483$

を満足することを特徴とする投影露光装置。

【請求項7】前記非球面を前記光学部材の屈折面に形成し、該屈折面の曲率をCとするとき、
 $|C| < 0.02$

を満足することを特徴とする請求項6に記載の投影露光装置。

【請求項8】前記投影光学系の最もマスク側の光学部材の屈折面から前記投影光学系の最も感光性基板側の光学部材の屈折面までの光軸に沿った長さをDとし、前記投影光学系の最もマスク側の光学部材の屈折面から前記非球面が形成される光学部材の屈折面までの光軸に沿った距離をdとするとき、
 $0 \leq d/D < 0.37$

の条件を満足することを特徴とする請求項6または請求項7に記載の投影露光装置。

【請求項9】前記非球面は、光軸からの高さをhとし、光軸からの高さhにおける非球面上の点からレンズ頂点での接平面までの光軸に沿った距離をX(h)、近軸の曲率半径をr、円錐定数をk、少なくとも1から12までの自然数をn、n次の非球面係数をCnとするとき、以下の式を満足する特徴とする請求項6から請求項8のいずれかに記載の投影露光装置。

$$X(h) = A / [1 + (1 - kA/r)^{0.5}] + C_1 h^1 + C_2 h^2 + C_3 h^3 + C_4 h^4 + \dots + C_n h^n$$

但し、 $A = h^2 / r$ である。

【請求項10】半導体素子を製造する方法において、露光光をマスク上に形成された所定のパターンに照明する工程と、

前記パターンを投影光学系を介して感光性基板に投影露光する工程とを有し、

前記投影光学系は、前記パターンの像を前記感光性基板に形成するための複数の光学部材を有し、

前記投影光学系に残存する収差成分を補正するための非球面を前記複数の光学部材の少なくとも1つに形成し、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、

$$0.02 < S(n-1)/\lambda < 0.483$$

を満足することを特徴とする半導体装置の製造方法。

【請求項11】前記非球面を前記光学部材の屈折面に形成し、該屈折面の曲率をCとするとき、

$$|C| < 0.02$$

を満足することを特徴とする請求項10に記載の半導体装置の製造する方法。

【請求項12】前記投影光学系の最もマスク側の光学部材の屈折面から前記投影光学系の最も感光性基板側の光学部材の屈折面までの光軸に沿った長さをDとし、前記投影光学系の最もマスク側の光学部材の屈折面から前記非球面が形成される光学部材の屈折面までの光軸に沿った距離をdとするとき、

$$0 \leq d/D < 0.37$$

の条件を満足することを特徴とする請求項10または請求項11に記載の半導体装置の製造方法。

【請求項13】前記非球面は、光軸からの高さをhとし、光軸からの高さhにおける非球面上の点からレンズ頂点での接平面までの光軸に沿った距離をX(h)、近軸の曲率半径をr、円錐定数をk、少なくとも1から12までの自然数をn、n次の非球面係数をC_nとするとき、以下の式を満足する特徴とする請求項10から請求項12のいずれかに記載の半導体装置の製造方法。

$$X(h) = A / [1 + (1 - kA/r)^{0.5}] + C_1 h^1 + C_2 h^2 + C_3 h^3 + C_4 h^4 + \dots + C_n h^n$$

但し、A = h² / r である。

【請求項14】複数の光学部材を用いて所定の順序で組み立てることにより、第1物体の像を第2物体上へ投影するための投影光学系を製造する方法において、

複数の光学部材を用いて前記投影光学系を組み立てるに先立って複数の光学部材の光学面の形状を計測する第1工程と、前記複数の光学部材を用いて投影光学系を組み立て中又は組み立て後に前記複数の光学部材の配置に関する情報を得る第2工程と、前記第1工程にて得られた前記複数の光学部材の光学面の形状に関する情報と、前記第2工程にて得られた前記複数の光学部材の配置に関する情報を得る工程とに基づいて、前記投影光学系に残存する収差を除去する非球面を前記複数の光学部材の少なくとも1つに形成する第3工程を有することを特徴とする投影光学系の製造方法。

【請求項15】前記第3工程にて形成される前記非球面は、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、

$$0.02 < S(n-1)/\lambda < 0.483$$

を満足することを特徴とする請求項14記載の投影光学系の製造方法。

【請求項16】前記非球面を前記光学部材の屈折面に形成し、該屈折面の曲率をCとするとき、

$$|C| < 0.02$$

を満足することを特徴とする請求項14または請求項15に記載の投影光学系の製造方法。

【請求項17】前記投影光学系の最も第1物体側の光学部材の屈折面から前記投影光学系の最も第2物体側の光学部材の屈折面までの光軸に沿った長さをDとし、前記投影光学系の最も第1物体側の光学部材の屈折面から前記非球面が形成される光学部材の屈折面までの光軸に沿った距離をdとするとき、

$$0 \leq d/D < 0.37$$

の条件を満足することを特徴とする請求項14から請求項16のいずれかに記載の投影光学系の製造方法。

【請求項18】前記非球面は、光軸からの高さをhとし、光軸からの高さhにおける非球面上の点からレンズ頂点での接平面までの光軸に沿った距離をX(h)、近軸の曲率半径をr、円錐定数をk、少なくとも1から12までの自然数をn、n次の非球面係数をC_nとするとき、以下の式を満足する特徴とする請求項14から請求項17のいずれかに記載の投影光学系の製造方法。

$$X(h) = A / [1 + (1 - kA/r)^{0.5}] + C_1 h^1 + C_2 h^2 + C_3 h^3 + C_4 h^4 + \dots + C_n h^n$$

但し、A = h² / r である。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、所定のパターンが形成されたマスクを感光性基板上に投影露光する投影露光装置、その投影光学系の製造等に関するものであり、特に、LSI等の半導体素子、液晶表示素子、又は薄膜磁気ヘッド等を製造するためのフォトリソグラフィ工程で用いられる投影露光装置等に好適なものである。

【0002】

【従来の技術】半導体素子、液晶表示素子、又は薄膜磁気ヘッド等を製造するために用いられる露光装置として、所定のパターンが形成された投影原版としてのマスクを投影光学系を介して感光性基板上に投影露光するものが知られている。この様な投影光学系としては、露光波長の光に対して透過性の光学特性を持つ屈折性の光学素子等のレンズで構成される屈折型の投影光学系、屈折性の光学素子としてのレンズと反射性の光学素子としてのミラーとを組み合わせた反射屈折型の投影光学系、さらには全て反射性の光学素子としてのミラーで構成される反射型の投影光学系が知られている。

【0003】以上の各投影光学系を用いてマスクパターンを感光性基板に投影する際の投影倍率としては、製造

する素子に応じて、縮小、等倍あるいは拡大するものがある。

【0004】

【発明が解決しようとする課題】以上の各種の素子を製造する際に用いられる露光装置の投影光学系は、微細なマスクパターンを感光性基板上に投影するために、一般に、高解像力で無収差に近い状態なる非常に高い光学性能が要求される。従って、近年にて要求される仕様を満たす投影光学系を実現するには、投影光学系を製造するための技術が1つの大きな要因となる。このため、投影光学系を構成する例えはレンズ等の光学部材自身の製造誤差、または投影光学系を製造する際に、複数の光学部材を組み込んだ段階で生ずる組立て製造誤差等による誤差をレンズ等の光学部材を保持する鏡筒内部のワッシャの厚み等を変更することにより、各光学部材の間隔を調整して、製造時に発生あるいは残存する低次の収差を補正することができる。

【0005】しかしながら、以上の従来の投影光学系の調整手法では、製造時に発生あるいは残存する高次の収差を補正することが不可能であった。すなわち、レンズ等の光学部材自身に残存する微小な製造誤差や、光学部材の間隔を調整しても残存する微小な収差成分（例えは、高次の像面弯曲、高次のディストーション等）等を取り除くことが困難であった。

【0006】従って、光学素子、組立調整した投影光学系が不良となる事態が頻繁に生じ、高い光学性能を有する投影光学系が設計できたとしても、投影光学系を製造することが極めて困難である。このため、ますます微細となるマスクパターンを投影光学系によって感光性基板上に投影露光して、より高い集積度を持つ半導体素子等の各種の素子を製造することは困難となる。

【0007】従って、本発明は、以上の課題に鑑みてなされたものであり、投影光学系を構成する光学部品の不良や、投影光学系自身の不良を招くことなく、高次の収差成分が除去された高い光学性能を持つ投影光学系の製造を可能とし得る。このため、本発明では、高次の収差成分が除去し得る投影光学系の製造方法、マスクパターンを感光性基板に良好に投影露光し得る投影露光装置、さらにはより高い集積度を持つ半導体素子を始めとした各種の素子の製造方法を提供することを目的とする。

【0008】

【課題を解決するための手段】以上の目的を実現するために、本発明の第1の態様によれば、マスク上に形成された所定のパターンを感光性基板に投影露光するための投影光学系の製造方法において、前記投影光学系を構成すべき複数の光学部材を製造する第1工程と、該第1工程によって製造された複数の光学部材の光学面の面形状をそれぞれ計測する第2工程と、前記第1工程にて製造された前記複数の光学部材を用いて投影光学系を組み立てる第3工程と、該第3工程後にて前記投影光学系に残

存する収差を計測するための第4工程と、該第4工程によって計測された収差を補正するために前記投影光学系を調整すると共に、該調整中又は調整完了時での前記投影光学系を構成する前記複数の光学部材間の光学面の間隔を求める第5工程と、前記第5工程後にて前記投影光学系に残存する高次の収差を計測する第6工程と、前記第2工程にて得られた各光学部材の面形状の情報と、前記第5工程にて得られた前記複数の光学部材間の光学面の間隔の情報と、前記投影光学系の光学設計情報に基づいて、前記第6工程にて得られた残存する高次収差量を補正する非球面を前記複数の光学部材の少なくとも1つに形成する第7工程とを有することである。

【0009】このとき、前記第7工程にて形成される前記非球面は、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、

$$0.02 < S(n-1) / \lambda < 0.483$$

を満足することが好ましい。

【0010】また、本発明の第2の態様によれば、露光光をマスク上に形成されたパターンに照明し、該パターンを投影光学系を介して感光性基板に露光する投影露光装置において、前記投影光学系は、前記パターンの像を前記感光性基板に形成するための複数の光学部材を有し、前記投影光学系に残存する収差成分を補正するための非球面を前記複数の光学部材の少なくとも1つに形成し、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、

$$0.02 < S(n-1) / \lambda < 0.483$$

を満足するものである。

【0011】また、本発明の第3の態様によれば、半導体装置の製造する方法において、露光光をマスク上に形成された所定のパターンに照明する工程と、前記パターンを投影光学系を介して感光性基板に投影露光する工程とを有し、前記投影光学系は、前記パターンの像を前記感光性基板に形成するための複数の光学部材を有し、前記投影光学系に残存する収差成分を補正するための非球面を前記複数の光学部材の少なくとも1つに形成し、前記投影光学系の光軸方向における前記非球面の最大変化量をSとし、露光波長をλ、前記非球面が形成されている前記光学部材の屈折率をnとするとき、

$$0.02 < S(n-1) / \lambda < 0.483$$

を満足することである。

【0012】また、本発明の第4の態様によれば、複数の光学部材を用いて所定の順序で組み立てることにより、第1物体の像を第2物体上へ投影するための投影光学系を製造する方法において、複数の光学部材を用いて前記投影光学系を組み立てるに先立って複数の光学部材の光学面の形状を計測する第1工程と、前記複数の光学

部材を用いて投影光学系を組み立て中又は組み立て後に前記複数の光学部材の配置に関する情報を得る第2工程と、前記第1工程にて得られた前記複数の光学部材の光学面の形状に関する情報と、前記第2工程にて得られた前記複数の光学部材の配置に関する情報を得る工程とに基づいて、前記投影光学系に残存する収差を除去する非球面を前記複数の光学部材の少なくとも1つに形成する第3工程を有するものである。

【0013】そして、以上の第1～第4の態様とも、前記非球面を前記光学部材の屈折面に形成し、該屈折面の曲率をCとするとき、

$$|C| < 0.02 \quad (1/\text{mm})$$

を満足することが望ましい。また、以上の第1～第4の態様とも、前記投影光学系の最も第1物体側（マスク側）の光学部材の屈折面から前記投影光学系の最も第2物体側（感光性基板側）の光学部材の屈折面までの光軸に沿った長さをDとし、前記投影光学系の最も第1物体側（マスク側）の光学部材の屈折面から前記非球面が形成される光学部材の屈折面までの光軸に沿った距離をdとするとき、

$$0 < d/D < 0.37$$

の条件を満足する構成としても良い。

【0014】

【発明の実施の形態】複数の光学部材を所定の順序で配置して投影光学系を組み立て、投影光学系を構成する複数の光学部材の少なくとも1つの位置を移動（光学部材間の間隔を変化、光学部材を光軸方向または光軸と直交する方向へ移動、さらには光学部材を傾斜等）させて組立て調整の完了後、あるいは複数の光学部材を用いて投影光学系を組み立て完了後（例えば、投影光学系の調整

$$(1) \quad 0.02 < S(n-1) / \lambda < 0.483$$

上記（1）式の下限を越えると、非球面としての効果が薄れるため好ましくない。上記（1）式の上限を越えると、非球面の屈折力が大きくなり過ぎるため、高次の収差をコントロールすることが困難となる。しかも、この場合、加工されるべき非球面の研磨上での要求される精度を出すことが困難となるため、非球面加工ができない。

$$(2) \quad |C| < 0.02 \quad (1/\text{mm})$$

上記（2）式の上限を越えると、非球面が形成されるべき屈折面での屈折力が大きくなるため、非球面の研磨上での要求される精度を出すことが困難となり、非球面加工が難しくなる。

【0018】また、投影光学系の最もマスク側の光学部材の屈折面から投影光学系の最も感光性基板側の光学部材の屈折面までの光軸に沿った長さをDとし、投影光学系の最もマスク側の光学部材の屈折面から非球面が形成される光学部材の屈折面までの光軸に沿った距離をdとするとき以下の条件（3）を満足することがより好ましい。

$$(3) \quad 0 \leq d/D < 0.37$$

を含めた投影光学系を組み立て工程等の完了後）において、本発明では、投影光学系に残存する高次の収差成分を、投影光学系内のある光学部材の光学面（屈折面等）を非球面（微小非球面）化することにより補正している。ここで言う非球面（微小非球面）とは、ある所望の仕様を持つ投影光学系を実現するために、設計時に積極的に収差を補正するために導入された非球面とは異なり、複数の光学部材を用いて投影光学系を組み立てて製造する、例えば組立て調整した際に、光学部品自体の製造誤差並びに投影光学系の調整誤差等により除去困難な残存する高次の収差を補正するものである。

【0015】この時の非球面は、複数の光学部材を用いて投影光学系を組み立た後に調整する、あるいは複数の光学部材を用いて投影光学系を組み立てる（例えば、投影光学系の調整を含めた投影光学系を組み立て工程等）に先立って複数の光学部材の光学面の形状を計測して得られた第1の情報と、複数の光学部材を用いて投影光学系を組み立て中または組み立て完了段階にて得られた複数の光学部材の配置に関する第2情報に基づいて決定される。この場合、複数の光学部材を用いた投影光学系の組み立てが完了した段階での投影光学系の残存収差を計測し、その計測された収差量は、上記第1及び第2情報を用いて非球面の形状、位置、数を決定する際の目標値とされることが好ましい。

【0016】ここで、本発明による非球面としては、投影光学系の光軸方向における前記非球面の最大変化量をSとし、前記非球面が形成されている前記光学部材の屈折率をnとするとき、以下の（1）式を満足することが好ましい。

$$(1) \quad 0.02 < S(n-1) / \lambda < 0.483$$

となる。

【0017】また、本発明による非球面を投影光学系を構成するある光学部材（レンズ）の少なくとも一方の屈折面（レンズ面、屈折性平面等）に形成し、その屈折面の近軸での曲率をCとするとき、以下の（2）式を満足することが望ましい。

$$(2) \quad |C| < 0.02 \quad (1/\text{mm})$$

上記（3）式は、高次の収差としてのディストーションや像面弯曲を良好に補正することができる投影光学系に対する非球面の最適な位置を規定するものである。

【0019】上記（3）式の上限及び下限を越えると、高次の収差としてのディストーションや像面弯曲を良好に補正することが困難となるため好ましくない。特に、高次の像面弯曲をより良好に補正するためには、投影光学系内の屈折面に形成される非球面は以下の（4）式を満足する位置に設けられることがより好ましい。

$$(4) \quad 0.05 < d/D < 0.37$$

また、高次のディストーションをよりバランス良く補正するためには、投影光学系内の屈折面に形成される非球面

面は以下の(5)式を満足する位置に設けられることがより好ましい。

$$(5) \quad 0 \leq d/D < 0.14$$

以上にて述べた本発明による非球面が光軸に対して回転対称な形状である場合には、その非球面は、例えば、光軸からの高さを h とし、光軸からの高さ h における非球

$$X(h) = A / [1 + (1 - k A/r)^{0.5}] + C_1 h^1 + C_2 h^2 + C_3 h^3 + C_4 h^4 + \dots + C_n h^n \quad \dots \dots \quad (6)$$

$$A = h^2 / r$$

また、本発明による非球面は、上記(6)式の奇数次の非球面係数を零として、以下の(6)の如く表現するこ

$$X(h) = A / [1 + (1 - k A/r)^{0.5}] + C_2 h^2 + C_4 h^4 + C_6 h^6 + C_8 h^8 + C_{10} h^{10} + \dots + C_{2i} h^{2i} \quad \dots \dots \quad (7)$$

$$A = h^2 / r$$

但し、 h は光軸からの高さ、 $X(h)$ は光軸からの高さ h における非球面上の点からレンズ頂点での接平面までの光軸に沿った距離、 r は近軸の曲率半径、 k は円錐定数、 i は自然数、 C_{2i} は $2i$ 次の非球面係数である。

【0022】ここで、光軸に対して回転対称な非球面形状を構成する場合、本発明による非球面は、少なくとも12次までの高次の項（上記(6)式では n を少なくとも1から12までの自然数とした時の高次の項、上記(7)式では i を少なくとも1から6までの自然数とした時の高次の項）を加味した形状とすることが好ましい。これにより、投影光学系に残存する高次の収差を補正することが可能となる。

【0023】また、本発明による非球面は、上記(6)式及び(7)式にて示した光軸に対して回転対称のみならず光軸に対して回転非対称の形状で構成されても良い事は言うまでもない。さて、次に本発明による実施例について添付図面を参照しながら説明する。図1には、投影光学系PLを備えた露光装置の様子を示す図である。

【0024】図1に示す如く、投影光学系PLの物体面には所定の回路パターンが形成された投影原版としてのマスク（レチクル）Rが配置されており、マスクRはマスクステージRSに保持されている。一方、投影光学系PLの像面には、感光性基板として、レジストが塗布されたウエハWが配置されており、このウエハWは投影光学系の光軸Axと直交する面内で2次元的に移動するウエハステージWSに保持されている。このウエハステージWSは、投影光学系の光軸Axと直交する面内で2次元的に移動するのみならず、さらに、投影光学系PLの像面（露光面）とウエハWの表面とを合致（合焦）させるために、投影光学系の光軸Axに移動可能に設けられており、投影光学系PLの像面（露光面）とウエハWの表面との合焦は、ウエハステージWSの斜め上方に配置された斜入射オートフォーカス系（AF1、AF2）によって光学的に検出される。

面上の点からレンズ頂点での接平面までの光軸に沿った距離を $X(h)$ 、近軸の曲率半径を r 、円錐定数を k 、自然数を n 、 n 次の非球面係数を C_n とするとき、次式(6)で表現することができる。

【0020】

ともできる。

【0021】

【0025】斜入射オートフォーカス系は、投射部AF1からの投射光がウエハWの表面にて反射される際に、検出部AF2にて受光される光の位置を検出することにより、投影光学系PLの像面（露光面）とウエハWの表面との合焦状態を光電的に検出する。なお、マスクステージRSは、マスクステージRSの位置を計測する干渉計と駆動モータを含む駆動系MRによって2次元的に移動し、ウエハステージWSは、ウエハステージWSの位置を計測する干渉計と駆動モータを含む駆動系MWによって2次元移動並びに光軸Axの方向へ移動する。そして、制御系MCは、マスクステージRSの位置を計測する駆動系MRの内部の干渉計からのウエハステージWSの位置情報に基づいて駆動系MRの駆動量を制御すると共に、ウエハステージWSの位置を計測する駆動系MWの内部の干渉計からのウエハステージWSの位置情報に基づいて駆動系MWの駆動量を制御する。さらに、制御系MCは、斜入射オートフォーカス系（AF1、AF2）からの出力に基づいてウエハステージWSの光軸Axに沿った方向での位置の制御を駆動系MWを介して行っている。

【0026】また、マスクRの上方には、マスクRを均一に照明するための照明光学系ISが設けられており、この照明光学系の内部には、248.4nmの露光波長の光を発振するエキシマレーザー光源が設けられている。そして、そのエキシマレーザー光源から供給されるレーザー光は、マスク上に所定の矩形状の照明領域を形成し、この時、投影光学系PLの瞳位置に設けられた開口絞りASの位置には、エキシマレーザーの光源像が形成され、所謂ケーラー照明がなされる。このように、ケーラー照明によって均一照明されたマスクRの像が投影光学系PLを通してウエハW上に露光（転写）される。

【0027】そして、ウエハW上におけるあるショット領域でのマスクR上のパターンの露光が完了すると、そのウエハW上の隣のショット領域へウエハステージを移

動させて、隣のショット領域での露光を行い、さらに隣へのショット領域への露光のためにウエハステージWSを順次移動させて露光を行う所謂ステップ・アンド・リピート方式で露光が行われる。

【0028】なお、本発明では、ステップ・アンド・リピート方式の露光装置に限ることなく、例えば、図19に示す如く、マスクR上のパターンを投影光学系PLを介してウエハ上に露光する際に、マスクステージRSとウエハステージWSとを相対的に移動、即ちマスクRとウエハWとを移動させて走査露光する走査型露光装置にも適用することができる。この場合の走査型露光装置は、照明光学系ISからの露光光によってスリット状（長方形状）または円弧状となる照明領域IFでマスクR上を照明し、これによって、ウエハW上にスリット状（長方形状）または円弧状となる露光領域EFを形成する構成とされることが望ましい。

【0029】以上の露光装置による露光の工程を経たウエハは、現像する工程を経てから現像したレジスト以外の部分を除去するエッチングの工程、エッチングの工程後の不要なレジストを除去するレジスト除去の工程等を経てウエハプロセスが終了する。そして、ウエハプロセスが終了すると、実際の組立工程にて、焼き付けられた回路毎にウエハを切断してチップ化するダイシング、各チップに配線等を付与するボンディング、各チップ毎にパッテージングするパッケージング等の各工程を経て、最終的に半導体装置（LSI等）が製造される。なお、以上には、投影露光装置を用いたウエハプロセスでのフォトリソグラフィ工程により半導体素子を製造する例を示したが、投影露光装置を用いたフォトリソグラフィ工程によって、半導体装置として、液晶表示素子、薄膜磁気ヘッド、撮像素子（CCD等）を製造することができる。

【0030】以上の図1に示した如き構成を持つ投影露光装置によるフォトリソグラフィ工程によって半導体装置等を製造することができるが、マスクRのパターンをウエハ上に投影する投影露光装置の投影光学系が高い光学性能を持つことがフォトリソグラフィ工程にて重要となる。そこで、投影露光装置用の投影光学系を製造する際での本発明における投影光学系の調整方法に関して図2を参照しながら説明する。

【0031】図2は本発明による投影露光装置用の投影光学系の製造する際の調整方法に関する手順を示す図である。

【ステップ1】ステップ1では、まず、図4に示す如く、所定の設計レンズデータによる設計値に従って投影光学系PLを構成する各光学部材としての各レンズ素子（L1～L5）、並びに各レンズを保持する保持枠、レンズ素子と保持枠とからなる保持ユニットを収納する鏡筒を製造する。すなわち、各レンズ素子（L1～L5）は、周知のレンズ加工機を用いて所定の光学材料からそ

れぞれ所定の設計値に従う曲率半径、軸上厚を持つよう加工され、また各レンズを保持する保持枠、レンズ素子と保持枠とからなる保持ユニットを収納する鏡筒は、周知の金属加工機等を用いて所定の保持材料（ステンレス、真鍮、セラミック等）からそれぞれ所定の寸法を持つ形状に加工される。

【ステップ2】ステップ2では、ステップ1にて製造された投影光学系PLを構成する各レンズ素子（L1～L5）のレンズ面の面形状を例えればフィゾー型の干渉計を用いて計測する。図6には、光学素子の表面の形状を計測するフィゾー型の干渉計の1例が示してある。図6に示す如く、633nmの波長入の光を発するHe-Ne気体レーザや363nmの波長入の光を発するArレーザ、248nmの波長入に高調波化されたArレーザ等のレーザ光源11からの光は、レンズ12を介してビームスプリッタ13を反射し、コリメータレンズ14によって平行光束に変換される。その平行光束は、集光レンズ15を介して被検物としてのレンズ18の被検面（レンズ面）Sを照射する。ここで、集光レンズ15には参照面が形成されており、光の1部は集光レンズ15の参照面で反射し、残りの光は集光レンズ15を通過して被検面Sで反射される。これらの反射光の波面は、それぞれ参照面と被検面Sの形状に応じた形状となる。これらの反射光は同一光路を辿って戻ることにより互いに重ね合わせられ、コリメータレンズ14、ビームスプリッタ13、結像レンズ16を介してCCD等の撮像装置17の撮像面にて結像される。この時、撮像装置17の撮像面には、両反射光の干渉による干渉縞が形成され、その干渉縞を計測することにより被検面Sの形状を正確に求めることができる。なお、フィゾー型の干渉計を用いてレンズ等の光学素子の表面（レンズ面）の形状を求めるることは公知であり、この事は、例えば、特開平6-126305号、特開平6-185997号等にて開示されている。

【0032】以上の如く、フィゾー型の干渉計を用いた光学素子の面形状の計測は、投影光学系PLを構成する各レンズ素子（L1～L5）の全てのレンズ面に関して行われる。そして、図3に示す如く、各計測した結果をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリ一部に記憶させる。

【ステップ3】ステップ2での投影光学系PLを構成する各レンズ素子（L1～L5）の全てのレンズ面の面形状の計測が完了した後、例えば、図4に示される如く、設計値に従って加工製造された光学ユニット、すなわち、レンズ等の光学素子（L1～L5）とその光学素子（L1～L5）を保持する保持枠（2A～2E）とで5つの光学ユニットそれぞれ組み上げる。そして、組み上げられた5つの光学ユニットを、鏡筒1の上部開口1aを介して順次、ワッシャ（3A～3E）を介在させながら鏡筒1内に落とし込むように組み上げていく。そし

て、最初に鏡筒1内に落としこまれた光学ユニット(L5、2E)は、鏡筒1の先端(ウエハ側)に形成された突出部1bにてワッシャ3Eを介して支持され、全ての光学ユニットが鏡筒1内に収容されることにより組み込む工程が完了する。この組み立て工程と平行して、保持ユニットと共に鏡筒内に収納されるワッシャ(3A～3E)の厚さを加味しながら工具(マイクロメータ等)を用いて、各レンズ素子の光学面(レンズ面)の間隔に関する情報を計測する。そして、投影光学系の組み上げ作業との計測作業とを交互に行なながら、ステップ3の組み上げ工程完了した段階での投影光学系PLの最終的な各レンズ素子の光学面(レンズ面)の間隔を求める。

【0033】このように、図3に示す如く、組み立て工程中または組み立て完了時での投影光学系PLの各レンズ素子の光学面(レンズ面)間の間隔に関する計測結果をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリ一部に記憶させる。なお、以上の組み込む工程に際して、必要に応じて光学ユニットを調整しても良い。このとき、例えば、ワッシャ(3A～3E)の交換により光学素子間の光軸方向での相対間隔を変化、あるいは光軸に対して光学素子を傾斜させる。また、鏡筒1の側面を貫通する雌螺子部を通して螺合するビスの先端が保持枠に当接するように鏡筒1を構成し、そのビスをドライバー等の工具を介して移動させることにより、保持部材間を光軸と直交する方向へずらし、偏心等の調整をしても良い。この事は、例えば特開平7-35963号公報に開示されている。

【0034】また、保持枠(2A～2E)は、1つの光学素子を保持するものに限らず、複数の光学素子を同時に保持する、即ちレンズ群を保持する構造であっても良い。また、図5に示す如く、各光学素子毎、または各レンズ群毎に光学素子を直接鏡筒(4A～4E)で保持し、その各鏡筒(4A～4E)をワッシャ(5A～5D)等を介在させながら積み上げて光学系を組み立てる、所謂分割鏡筒方式で投影光学系PLを組み上げても良い。

【ステップ4】次に、ステップ4では、図4又は図5に示す如く、ステップ3にて組み上がった投影光学系PLに残存する低次の収差を計測する。

【0035】具体的には、一旦、投影光学系を図1に示す如き投影露光装置本体(又は投影露光装置本体と同じ構成を持つ検査機)に取りつけ、図7及び図8に示す如きテストマスク(TR1、TR2)を用いて、各種の収差(球面収差、コマ収差、非点収差、像面弯曲、歪曲収差等)を測定する。収差測定の一例として、像面弯曲の測定の場合には、図1に示す如き装置(または図1に示す構成を持つ検査機)に検査対象の投影光学系PLを取りつけると共に、図7に示すテストマスクTR1をマスクステージRSに保持する。この時のテストマスクTR1は、XY平面内にて複数のマークが形成されたテスト

パターン領域PA1とその周辺に形成された遮光帯LSTとを有しており、そのテストパターン領域PA1には、例えば、Y方向に所定のピッチを持つY方向マークM₁と、X方向に所定のピッチを持つX方向マークM₂と、XY方向に対して斜め45度の方向に沿って所定のピッチを持つ斜め方向マーク(M₃、M₄)との4つのマークを持つマーク群が17か所に形成されている。

【0036】図7に示す如きテストマスクTR1を用いて、そのテストマスクTR1を検査対象の投影光学系PLを介して感光性基板としてのウエハ上所定のショット領域に焼き付ける。そして、ウエハステージWSを2次元的に移動させて投影光学系の露光領域を、上記所定のショット領域とは異なるショット領域に位置させ、斜入射オートフォーカス系(AF1、AF2)を用いてウエハステージWSを光軸Axの方向に沿って所定量だけ移動させて当該異なるショット領域にテストマスクTR1の像を焼き付ける。この様に、ウエハステージWSの2次元的な移動、光軸方向でのウエハステージWSの移動、露光の動作を繰り返して、投影光学系PLの光軸方向に沿った複数の位置でのテストマスクTR1の焼き付けを行う。なお、ショット領域の数が1つのウエハに収まらない場合には、別のウエハをウエハステージWS上に載置する動作を挟んでも良い。

【0037】次に、実際にウエハW上に焼き付けられたパターンの各マーク像に基づいて、各マークの最良像の位置(露光領域内での位置および光軸方向での位置)を、電子顕微鏡等を用いて、焼き付けた全てのウエハに関して求めることにより、図9に示す如く、検査対象の投影光学系PLの像面弯曲量を検出することができる。ここで、図9は、横軸に像高、縦軸にディフォーカス量を取った時の像面弯曲を示しており、図9の曲線aは、ステップ3にて組み上がった投影光学系PLに残存する像面弯曲を示している。この曲線aは、図7に示すテストマスクTR1を用いて実際にウエハWを試し焼きして得られた結果、すなわち最良マーク像の位置をプロットしたものである。

【0038】また、歪曲収差の測定の場合には、図1に示す如き装置(または図1に示す構成を持つ検査機)に検査対象の投影光学系PLを取りつけると共に、図8に示すテストパターンをマスクステージRSに保持する。この時のテストマスクTR2は、XY平面内にて複数のマークが形成されたテストパターン領域PA2とその周辺に形成された遮光帯LSTとを有しており、そのテストパターン領域PA2には、例えば、十字上の直交型のマーク(M_{0,0}～M_{8,8})がX方向並びにY方向において等間隔となるように81か所に形成されている。その後、実際のテストパターンを検査対象の投影光学系PLを介して感光性基板としてのウエハ上に焼き付ける。このとき、ウエハ表面は投影光学系PLの最良像面に位置するように斜入射オートフォーカス系(AF1、AF2)

2)を用いてウエハステージWSの位置を設定する。そして、実際に焼き付けられたパターンの各マーク位置と焼き付けられるべき各マークの理想的な位置（設計値による各マーク位置）とのずれ量を電子顕微鏡等を用いて求めることにより、検査対象の投影光学系PLの歪曲収差量を検出することができる。

【0039】ここで、図10は、横軸に像高、縦軸にディフォーカス量を取った時の歪曲収差を示しており、図10の曲線aは、ステップ3にて組み上がった投影光学系PLに残存する像面弯曲を示している。この曲線bは、図7に示すテストマスクTR1を用いて実際にウエハWを試し焼きして得られた結果、即ち設計値に対する各マーク位置のずれ量を各像高についてプロットしたものである。

【0040】なお、以上では、諸収差を計測するために実際に露光を行った例を述べたが、投影面上のCCD等の撮像素子を配置して、その撮像素子と電気的に接続されたCRTモニター等の表示装置を介して、テストマスク(TR1、TR2)の各マーク像の様子から諸収差量を求めて良い。この収差計測工程において、図3に示す如く、計測された投影光学系PLに残存する諸収差に関する収差量に関する情報をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリ一部に記憶させる。

【ステップ5】ステップ5は、以下に説明するサブステップ5aとサブステップ5bをと含むものであり、これらのサブステップ5a、5bは、ステップ5の中で平行して行われる。

【サブステップ5a】サブステップ5aでは、ステップ4にて計測された投影光学系PLに残存する低次の収差を除去するために、投影光学系PLを調整する。

【0041】まず、投影光学系PLの調整に先立って、コンピュータ、計算機等の演算系7は、図3に示す如く、メモリ一部内に記憶された各情報、即ちステップ2にて得られた各光学素子の面形状に関する情報およびステップ3の組み立て工程にて得られた各光学素子の光学面の間隔に関する情報等に基づいて、メモリ一部内に予め記憶された光学基本データを修正して、実際に組み上がった投影光学系PLの製造過程での光学データを再現する。その後、演算系7は、メモリ一部内に記憶された情報としてステップ4にて得られた投影光学系PLに残存する諸収差に関する収差量に関する情報を、実際に組み上がった投影光学系PLの製造過程での光学データに基づいて、収差が補正し得る各光学素子の光学面の間隔（以下、光学面の間隔補正量と呼ぶ）を算出し、不図示のCRTモニター等の表示系8にて、各光学素子の光学面の間隔補正量等の情報を表示する。

【0042】次に、コンピュータ等の演算系7にて算出された各光学素子の光学面の間隔補正量に基づいて、図4または図5に示した検査対象となる投影光学系PL内

部のワッシャ（3A～3E、5A～5D）の交換により光学素子間の光軸方向での相対間隔を変化、あるいは光軸に対して光学素子を傾斜させる。また、鏡筒1の側面を貫通する雌螺子部を通して螺合するビスの先端が保持枠に当接するように構成し、そのビスをドライバー等の工具を介して移動させることにより、保持部材間を光軸と直交する方向へずらす。これらの調整手法を行うことにより投影光学系PLを調整がなされ、例えば、図9、図10の各曲線aに示す如き像面弯曲、歪曲収差等の低次の収差が除去される。

【0043】なお、投影光学系PLの調整に際しては、必要に応じて投影光学系PLの1部または全部を分解し、ワッシャ（3A～3E、5A～5D）、あるいは光学ユニットの交換を行って、再度、投影光学系PLを組み上げる。

【サブステップ5b】このサブステップ5bでは、以上の如きサブステップ5aの調整工程と平行して、投影光学系PLの各レンズ素子の光学面（レンズ面）の間隔に関する情報を求める。すなわち、投影光学系PLの調整工程時において、保持ユニットと共に鏡筒内に収納されるワッシャ（3A～3E、5A～5D）の厚さを加味しながら工具（マイクロメータ等）を用いて各レンズ素子の光学面（レンズ面）の間隔を計測する。そして、サブステップ5aの調整作業とサブステップ5bの計測作業とを交互に行なながら、サブステップ5aの調整工程が完了した時の投影光学系PLの最終的な各レンズ素子の光学面（レンズ面）の間隔を求める。

【0044】このように、図3に示す如く、調整工程中または調整完了時での投影光学系PLの各レンズ素子の光学面（レンズ面）間の間隔に関する計測した結果（各レンズ素子の光学面（レンズ面）の間隔に関する情報）をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリ一部に記憶させる。

【ステップ6】ステップ5において投影光学系PLにて残存する低次の収差が投影光学系PLの調整によって除去された後に、ステップ6においては、光学素子の製造誤差（例えば、所定の曲率半径を持つ球面レンズで構成されるレンズ素子が製造誤差により微小な凹凸を持つ微小非球面レンズで構成されること等）、またはステップ3の調整にて除去できない投影光学系の製造段階で生ずる組立製造誤差等が起因して投影光学系PLに残存する高次の収差を測定する。

【0045】収差の測定は、ステップ4にて述べたのと同様であるため詳細な説明は省略するが、例えば、テストマスク(TR1、TR2)を用いて、検査対象の投影光学系PLを介して感光性基板としてのウエハ上に焼き付ける。実際にウエハW上に焼き付けられたパターンの各マーク像を、電子顕微鏡等を用いて、焼き付けた全てのウエハに関して検査することにより、検査対象の投影光学系PLの高次の各収差を検出する。例えば、図9、

図10の各曲線bに示す如き像面弯曲、歪曲収差等の高次の収差が計測される。

【0046】このステップ6の高次の収差計測工程において、図3に示す如く、計測された投影光学系PLに残存する高次の収差量に関する情報をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリ一部に記憶させる。

〔ステップ7〕ステップ6にて得られた残存する高次収差量を補正する微小非球面を前記複数の光学部材の少なくとも1つに形成するためには、投影光学系PLの各光学部材の面形状の情報と、調整完了段階での投影光学系PLの複数の光学部材間の最終的な光学面の間隔の情報と、投影光学系の光学基本設計データ等の光学設計に関する情報に基づいて、ステップ5での調整完了時の投影光学系PLの製造光学データを再現することが必要である。

【0047】このため、ステップ7は、前述のステップ2にて得られた各光学部材の面形状の情報と、前述のステップ5にて得られた複数の光学部材間の光学面の間隔の情報と、投影光学系の光学設計情報に基づいて、ステップ6にて得られた残存する高次収差量を補正する微小非球面を前記複数の光学部材の少なくとも1つに形成するものである。

【0048】この時の本ステップ7は、ステップ6にて計測された検査対象の投影光学系PLの高次の各収差を補正し得る非球面の位置、非球面の形状、非球面の数を決定する第1のサブステップ、その第1のサブステップの後、非球面加工すべき光学素子を取り出し、レンズ研磨加工機を用いて非球面加工を行う第2のサブステップ、第2のサブステップの後に、非球面加工された光学素子を投影光学系PLに組み込み調整する第3のサブステップを有している。

〔第1のサブステップ〕まず、ステップ2にて計測された各レンズ素子のレンズ面の面形状の情報、ステップ6にて求められた調整完了した時の投影光学系PLの各レンズ素子の光学面（レンズ面）の間隔に関する情報、並びに投影光学系PLの光学設計情報に基づいて、ステップ7にて計測された検査対象の投影光学系PLの高次の各収差を補正し得る非球面を決定する。

【0049】例えば、コンピュータ等の演算系7は、ステップ6にて計測された検査対象の投影光学系PLの高次の各収差に関する情報を用いて、ステップ5の調整工程に先立って得られた投影光学系PLの製造光学データに関する情報（ステップ2にて得られた各光学素子の面形状に関する情報およびステップ3の組み立て工程にて得られた各光学素子の光学面の間隔に関する情報等に基づいて、修正された投影光学系PLの組上げ時の光学データの情報）を再修正して、ステップ5の調整工程完了後の投影光学系PLの製造過程での光学データを再現する。

【0050】なお、ステップ5の調整工程に先立って得られた投影光学系PLの製造光学データに関する情報を用いることなく、ステップ2にて計測された各レンズ素子のレンズ面の面形状の情報、ステップ3の組み立て工程にて得られた各光学素子の光学面の間隔に関する情報、ステップ5にて求められた調整完了した時の投影光学系PLの各レンズ素子の光学面（レンズ面）の間隔に関する情報を新たに用いて、ステップ5の調整工程完了後の投影光学系PLの製造過程での光学データを再現しても良い。また、組み立て工程及び調整工程を経た時の投影光学系PLの各レンズ素子の光学面（レンズ面）の間隔又は間隔変化量に関する履歴をコンソール等の入力系を介してコンピュータ計算機等の演算系7のメモリ一部に記憶させ、その履歴から調整完了した時の投影光学系PLの各レンズ素子の光学面（レンズ面）の間隔を求める、それを各レンズ素子のレンズ面の面形状の情報として用いても良い。

【0051】次に、以上の如き再現された調整完了時の製造光学データと、メモリ一部に記憶された情報としてステップ6にて得られた投影光学系PLに残存する高次の諸収差に関する収差量に関する情報に基づき、コンピュータ等の演算系7は光線追跡を行って、投影光学系PLに残存する高次の各収差を補正できるような微小非球面の位置、形状、非球面の数を決定する。

〔第2のサブステップ〕さて、コンピュータ等の演算系7を用いた光線追跡により求められた微小非球面を投影光学系PLに形成するために、必要に応じて投影光学系PLの1部または全部を分解し、非球面加工を施すべき光学ユニットを取り出す。その後、光学ユニット内の光学素子の取り出した後に、光学素子の加工面に対して非球面加工をレンズ研磨加工機により行う。

【0052】図11は、レンズ研磨加工機の構成を示すものであり、コンピュータ等の演算系7を用いて算出された非球面加工データをレンズ研磨加工機の入力系31を介して制御部20へ入力する。図11に示す如く、被加工対象としてのレンズ素子（光学素子）10は、XY方向に移動可能な移動ステージ21上に載置されており、その端部が例えばピン21aに当接している。なお、図11では、レンズ面等の光学面の屈折力が非常に弱い屈折性のレンズを被加工対象とした例を示しているが、レンズ面等の光学面の屈折力が零の光透過性の平行平面板を被加工対象とすることもできる。さらには、レンズ面等の光学面の屈折力が強い屈折性のレンズを被加工対象としても良いが、製造上を考慮すると、できるだけレンズ面等の光学面の屈折力が弱い光学部材を加工対象とすることが望ましい。

【0053】また、ステージ21をXY方向へ2次元的に移動させるために駆動部22は、制御部20によって制御されている。駆動部22を介してステージ21を移動させる際に、ステージ21のXY方向の位置を検出す

るために、エンコーダ、干渉計等からなる位置検出部30がステージ21の左端側に設けられており、この位置検出部30からの検出信号は制御部20へ伝達される。

【0054】また、研磨皿23は、保持部24を介して回転軸25の一端に取り付けられており、図中のZ方向を軸として回転可能である。この回転軸25の他端には、制御部20によって制御されるモータ26が取り付けられている。回転軸25を回転自在に支持する軸受27は、不図示の本体に固設されている支持部28に対してZ方向へ移動可能に設けられている。この支持部28には、制御部20により制御されるモータ29が取り付けられており、このモータ29の作用により軸受け27がZ方向に沿って移動し、ひいては研磨皿23がZ方向へ移動する。なお、研磨皿23を保持する保持部24には、研磨皿23と被加工物としてのレンズ素子10との接触圧を検出するためのセンサ(不図示)が設けられており、このセンサからの接触圧に関する出力は制御部29へ伝達される。

【0055】ステップ5におけるレンズ研磨加工機の動作について説明すると、まず、上述した如く、投影光学系PLの高次の各収差を補正し得る光学素子に関する微小非球面の加工量、即ちコンピュータ等の計算系7を用いて算出された非球面加工データをレンズ研磨加工機の入力系31を介して制御部20へ入力すると共に、被加工物としての光学素子10を図11中のレンズ研磨加工機のステージ21上に保持する。

【0056】次に、制御部20は、モータ26を介して研磨皿23を回転させつつ駆動部22を介してステージ21のXY方向に沿って移動させる。すなわち、研磨皿23は、被加工物としての光学素子10の加工面10aに沿ってなぞるように移動する。このとき、加工面10aにおける研磨量は、加工面10aと研磨皿23との接触圧、及び研磨皿23の滞留時間で決定される。

【第3のサブステップ】以上のレンズ研磨加工機による加工が完了すると、被加工物としての光学素子10は、蒸着工程等により反射防止膜が施された後、保持枠が取り付けられる。そして、最終的に、レンズ研磨加工機により非球面加工された光学素子を保持する光学ユニットを投影光学系PLに組み込む。このとき、必要に応じて図4または図5に示した検査対象となる投影光学系PL内部のワッシャ(4A~4E、5A~5D)の交換により光学素子間の光軸方向での相対間隔を微調整、あるいは光軸に対して光学素子を傾斜させたり、また保持枠間を光軸と直交する方向へずらす。これらの調整手法を行うことにより投影光学系PLを調整がなされ、例えば、図9、図10に示す如き像面弯曲、歪曲収差等の高次の収差が除去され、所望の結像性能を持つ投影光学系PLの製造が達成される。

【0057】

【実施例】次に、以上の各ステップにより製造される投

影光学系PLに関して具体的に説明する。図12には、照明光学装置IS内部に配置される光源として、248.4nmの露光波長入を持つ光を供給するエキシマレーザとしたときの投影光学系のレンズ構成の例を示している。

【0058】図12に示す如く、本例での投影光学系は、第1物体としてのレチクルR側より順に、正の屈折力を持つ第1レンズ群G₁と、負の屈折力を持つ第2レンズ群G₂と、正の屈折力を持つ第3レンズ群G₃と、負の屈折力を持つ第4レンズ群G₄と、正の屈折力を持つ第5レンズ群G₅と、正の屈折力を持つ第6レンズ群G₆とを有している。

【0059】まず、正の屈折力を持つ第1レンズ群はテレセントリック性を維持しながら主にディストーションの補正に寄与しており、具体的には、第1レンズ群にて正のディストーションを発生させて、この第1レンズ群よりも第2物体側に位置する複数のレンズ群にて発生する負のディストーションをバランス良く補正している。負の屈折力を持つ第2レンズ群及び負の屈折力を持つ第4レンズ群は、主にペツツバール和の補正に寄与し、像面の平坦化を図っている。負の屈折力を持つ第2レンズ群及び正の屈折力を持つ第3レンズ群では、この2つのレンズ群において逆望遠系を形成しており、投影光学系のバックフォーカス(投影光学系の最も第2物体側のレンズ面等の光学面から第2物体までの距離)の確保に寄与している。正の屈折力を持つ第5レンズ群及び同じく正の屈折力を第6レンズ群は、ディストーションの発生を抑えることと、第2物体側での高NA化に十分対応するために特に球面収差の発生を極力抑えることとに主に寄与している。

【0060】このとき、第1レンズ群の焦点距離をf₁とし、第2レンズ群の焦点距離をf₂、第3レンズ群の焦点距離をf₃、第4レンズ群の焦点距離をf₄、第5レンズ群の焦点距離をf₅、第6レンズ群の焦点距離をf₆、第1物体面から第2物体面までの距離をLとするとき、以下の条件(8)~(11)を満足することがより望ましい。

$$(8) \quad 0.1 < f_1 / f_3 < 1.7$$

$$(9) \quad 0.1 < f_2 / f_4 < 1.4$$

$$(10) \quad 0.01 < f_5 / L < 0.9$$

$$(11) \quad 0.02 < f_6 / L < 1.6$$

条件(8)では、正の屈折力の第1レンズ群の焦点距離f₁と正の屈折力の第3レンズ群の焦点距離f₃との最適な比率、即ち、第1レンズ群と第3レンズ群との最適な屈折力(パワー)配分を規定している。この条件

(8)は、主にディストーションをバランス良く補正するためのものであり、この条件(8)の下限を越えると、第3レンズ群の屈折力が第1レンズ群の屈折力に対して相対的に弱くなるため、負のディストーションが大きく発生する。また、条件(8)の上限を越えると、第1レンズ群の屈折力が第3レンズ群の屈折力に対して相

対的に弱くなるため、負のディストーションが大きく発生する。

【0061】条件(9)では、負の屈折力の第2レンズ群の焦点距離 f_2 と負の屈折力の第4レンズ群の焦点距離 f_4 との最適な比率、即ち、第2レンズ群と第4レンズ群との最適な屈折力(パワー)配分を規定している。この条件(9)は、主にペツツバール和を小さくして、広い露光フィールドを確保しながら、像面湾曲を良好に補正するためのものであり、この条件(9)の下限を越えると、第4レンズ群の屈折力が第2レンズ群の屈折力に対して相対的に弱くなるため、正のペツツバール和が大きく発生する。また、条件(9)の上限を越えると、第2レンズ群の屈折力が第4レンズ群の屈折力に対して相対的に弱くなるため、正のペツツバール和が大きく発生する。なお、第4レンズ群の屈折力を第2レンズ群の屈折力に対して相対的に強くして、広い露光フィールドのもとでペツツバール和をよりバランス良く補正するためには、上記条件(9)の下限値を0.8として、 $0.8 < f_2 / f_4$ とすることが好ましい。

【0062】条件(10)では、正の屈折力の第5レンズ群の焦点距離 f_5 と第1物体(レチクル等)と第2物体(ウェハ等)までの距離(物像間距離) L との最適な比率を規定している。この条件(10)は、大きな開口数を保ちながら球面収差、ディストーション及びペツツバール和をバランス良く補正するためのものである。この条件(10)の下限を越えると、第5レンズ群の屈折力が大きくなり過ぎ、この第5レンズ群にて負のディストーションのみならず負の球面収差が甚大に発生する。この条件(10)の上限を越えると、第5レンズ群の屈折力が弱くなり過ぎ、これに伴って負の屈折力の第4レンズ群の屈折力も必然的に弱くなり、この結果、ペツツバール和を良好に補正することができない。

【0063】条件(11)では、正の屈折力の第6レンズ群の焦点距離 f_6 と、第1物体(レチクル等)から第2物体(ウェハ等)までの距離(物像間距離) L との最適な比率を規定している。この条件(11)は、大きな開口数を保ちながら高次の球面収差及び負のディストーションの発生を抑えるためのものである。この条件(11)の下限を越えると、第6レンズ群自身にて負のディストーションが大きく発生し、この条件(11)の上限を越えると、高次の球面収差が発生する。

【0064】さて、図11に示した本例の投影光学系PLに関する諸元の値を以下の表1に掲げ、また表1に示す投影光学系PLに関する上記条件(8)～(11)の条件対応値を表2に掲げる。但し、左端の数字は物体側(レチクル側)からの順序を表し、 r はレンズ面の曲率半径、 d はレンズ面間隔、 n は露光波長入が248.4nmにおける合成石英 SiO_2 の屈折率、 d_0 は第1物体(レチクル)から第1レンズ群G1の最も物体側(レチクル側)のレンズ面(第1レンズ面)までの距離、 B_f は第

6レンズ群G6の最も像側(ウェハ側)のレンズ面から像面(ウェハ面)までの距離、 B は投影光学系の投影倍率、NAは投影光学系の像側での開口数、 L は物体面(レチクル面)から像面(ウェハ面)までの物像間距離、 f_1 は第1レンズ群G1の焦点距離、 f_2 は第2レンズ群G2の焦点距離、 f_3 は第3レンズ群G3の焦点距離、 f_4 は第4レンズ群G4の焦点距離、 f_5 は第5レンズ群G5の焦点距離、 f_6 は第6レンズ群G6の焦点距離を表している。

【0065】

【表1】

$d_0 = 105.99385$			40	-212.37919	1.14438	
$B = 1/5$			41	-3009.97000	23.00000 1.50839 (L ₅₁)	
$NA = 0.55$			42	-312.33647	2.92283	
$B_f = 28.96856$			43	401.05778	37.00000 1.50839 (L ₅₂)	
$L = 1200$			44	-361.42967	12.43498	
	r	d	n			
1	723.32335	28.00000	1.50839 (L ₁₁)	45	-231.63315	27.00000 1.50839 (L ₅₃)
2	-571.27029	2.00000		46	-319.48896	1.10071
3	-8470.94995	20.00000	1.50839 (L ₁₂)	47	355.64919	25.00000 1.50839 (L ₅₄)
4	324.13159	7.92536		48	3678.53000	4.83032
5	360.44110	28.00000	1.50839 (L ₁₃)	49	177.43364	32.00000 1.50839 (L ₅₅)
6	-432.97069	1.04750		50	553.83964	3.29194
7	397.04484	27.00000	1.50839 (L ₁₄)	51	137.68248	39.90000 1.50839 (L ₅₆)
8	-825.96923	0.97572		52	330.86342	9.82671
9	214.74004	31.00000	1.50839 (L ₂₁)	53	587.42747	23.00000 1.50839 (L ₅₇)
10	110.51892	24.04713		54	81.23164	7.04896
11	229.41181	26.00000	1.50839 (L ₂₂)	55	93.74477	71.00000 1.50839 (L ₅₈)
12	-396.52854	1.10686		56	1555.42999	
13	-1014.34000	17.00000	1.50839 (L ₂₃)			
14	137.90605	18.76700				
15	-418.55207	12.90000	1.50839 (L ₂₄)			
16	138.89479	26.88549				
17	-133.71351	15.00000	1.50839 (L ₂₅)			
18	561.35918	52.53782				
19	1381.31000	35.00000	1.50839 (L ₂₆)			
20	-188.69074	14.91509				
21	-134.03345	22.80000	1.50839 (L ₂₇)			
22	-198.69180	2.79782				
23	-3029.37000	27.00000	1.50839 (L ₂₈)			
24	-333.96362	2.87255				
25	905.53484	28.00000	1.50839 (L ₂₉)			
26	-611.80005	2.49780				
27	254.70879	30.00000	1.50839 (L ₃₀)			
28	3936.53000	1.64701				
29	239.51669	31.00000	1.50839 (L ₃₁)			
30	-1238.94000	5.60527				
31	-2379.42001	21.00000	1.50839 (L ₃₂)			
32	150.43068	9.76890				
33	209.21387	17.00000	1.50839 (L ₃₃)			
34	149.67785	31.54706				
35	-199.55198	15.90000	1.50839 (L ₃₄)			
36	341.76300	57.70880				
37	-170.75300	18.00000	1.50839 (L ₃₅)			
38	-3700.60999	6.28784				
39	-1025.75000	23.00000	1.50839 (L ₃₆)			

図12に示す如く、表1の投影光学系は、第1物体としてのレチクルR側より順に、正の屈折力を持つ第1レンズ群G₁と、負の屈折力を持つ第2レンズ群G₂と、正の屈折力を持つ第3レンズ群G₃と、負の屈折力を持つ第4レンズ群G₄と、正の屈折力を持つ第5レンズ群G₅と、正の屈折力を第6レンズ群G₆とを有し、物体側(レチクルR側)及び像側(ウェハW側)においてほぼテセントリックとなっており、縮小倍率を有するものである。なお、図12に示す各実施例の投影光学系は、それぞれ物像間距離(物体面から像面までの距離、またはレチクルRからウェハWまでの距離)Lが1200、像側の開口数NAが0.55、投影倍率Bが1/5、ウェハW上での露光領域の直径が31.2である。

【0067】図12に示した投影光学系の具体的なレンズ構成を説明すると、まず、第1レンズ群G₁は、物体側から順に、像側に凸面を向けた形状の正レンズ(両凸形状のレンズ)L₁₁と、物体側に凸面を向けたメニスカス形状の負レンズL₁₂と、両凸形状の2枚の正レンズ(L₁₃、L₁₄)とを有している。そして、第2レンズ群G₂は、最も物体側に配置されてその像側に凹面を向けた負メニスカスレンズ(前方レンズ)L_{2F}と、最も像側に配置されて物体側に凹面を向けた負メニスカスレンズ(後方レンズ)L_{2R}と、第2レンズ群G₂内の最も物体側に位置する負メニスカスレンズL_{2F}と第2レンズ群内の最も像側に位置する負メニスカスレンズL_{2R}との間に配置されて負の屈折力を持つ中間レンズ群G_{2M}とから構成

されている。

【0068】その中間レンズ群G_{2M}は、物体側から順に、両凸形状の正レンズ（第1レンズ）L_{M1}と、像側により強い曲率の面を向けた負レンズ（第2レンズ）L_{M2}と、両凹形状の負レンズ（第3レンズ）L_{M3}、物体側により強い曲率の面を向けた負レンズ（第4レンズ）L_{M4}、像側により強い曲率の面を向けた正レンズ（第5レンズ）L_{M5}から構成されている。

【0069】また、第3レンズ群G₃は、像側により強い曲率の面を向けた正レンズ（正メニスカスレンズ）L₃₁と、両凸形状の正レンズL₃₂と、物体側に凸面を向けた正レンズ（正メニスカスレンズ）L₃₃と、物体側により強い曲率の面を向けた正レンズL₃₄とから構成されており、第4レンズ群G₄は、像側に凹面を向けた負レンズL₄₁と、像側に凹面を向けた負メニスカスレンズL₄₂と、両凹形状の負レンズL₄₃と、物体側に凹面を向けた負レンズL₄₄とから構成されている。

【0070】ここで、第4レンズ群G₄中の負レンズL₄₁の像側の凹面と、負メニスカスレンズL₄₄の物体側の凹面との間の光路中には、開口絞りASが配置される。第5レンズ群G₅は、像側に凸面を向けた正メニスカスレンズL₅₁と、像側により強い曲率の面を向けた正レンズL₅₂と、両凸形状の正レンズL₅₃と、物体側に凸面を向けた負メニスカスレンズL₅₄と、物体側により強い曲率の面を向けた正レンズL₅₅と、物体側に凸面を向けた正メニスカスレンズL₅₆と、物体側により強い曲率の面を向けた正レンズ（正メニスカスレンズ）L₅₇と、像側に凹面を向けた負レンズ（負メニスカスレンズ）L₅₈とから構成され、第6レンズ群G₆は、物体側に凸面を向けた厚肉の正レンズL₆₁のみから構成される。

【0071】ここで、第1レンズ群G₁においては、物体側に凸面を向けたメニスカス形状の負レンズL₁₂の像側のレンズ面と、両凸形状の正レンズL₁₃の物体側のレンズ面とが同程度の曲率を有しかつ比較的の近接しているため、これらの2つのレンズ面が高次のディストーションを補正している。また、第2レンズ群G₂の最も物体側に配置される負の屈折力を持つ前方レンズL_{2F}が像側に凹面を向けたメニスカス形状で構成されているため、コマ収差の発生を軽減することができ、中間レンズ群G_{2M}の正の屈折力を持つ第1レンズL_{M1}が像側に凸面を向けた形状のみならず物体側にも凸面を向けた両凸形状で構成されているため、瞳の球面収差の発生を抑えることができる。また、中間レンズ群G_{2M}の正の屈折力を持つ第5レンズL_{M5}が、その像側に配置される負の屈折力を持つ後方レンズL_{2R}の凹面と対向する凸面を有するため、非点収差を補正することができる。

【0072】また、第4レンズ群G₄では、負レンズ（両凹形状の負レンズ）L₄₃の物体側に凹面を像側に向けた負レンズL₄₁を配置し、負レンズ（両凹形状の負レンズ）L₄₃の像側に凹面を物体側に向けた負レンズL₄₄を

配置する構成であるため、コマ収差の発生を抑えつつペッツバール和を補正することができる。また、第4レンズ群G₄中の負レンズL₄₁の像側の凹面と負レンズL₄₄の物体側の凹面との間に開口絞りASを配置することによって、第3レンズ群G₃から第6レンズ群G₆までのレンズ群を開口絞りASを中心にして、多少縮小倍率を掛けつつ対称性をあまり崩さずに構成できるため、非対称収差、特にコマ収差やディストーションの発生を抑制することができる。

【0073】また、第5レンズ群G₅中の正レンズL₅₃が、負メニスカスレンズL₅₄に対向する凸面を有し、かつ負メニスカスレンズL₅₄と反対側のレンズ面も凸面である両凸形状であるため、高NA化に伴う高次の球面収差の発生を良好に抑えることができる。さて、次に、表1に示す基本設計データに基づく投影光学系PLを製造する工程についての実施例を説明する。

【ステップ1】図2に示した如く、前述のステップ1にて、表1に示すレンズデータを満たす投影光学系PLを構成する各レンズ並びに各レンズを保持する保持棒、レンズと保持棒とからなる保持ユニットを収納する鏡筒を製造する。すなわち、各レンズは、周知のレンズ加工機を用いて所定の光学材料（石英）からそれぞれ所定の曲率半径、所定の軸上厚を持つように加工され、また各レンズを保持する保持棒、レンズと保持棒とからなる保持ユニットを収納する鏡筒は、周知の金属加工機等を用いて所定の保持材料（ステンレス、真鍮、セラミック等）からそれぞれ所定の寸法を持つ形状に加工される。

【ステップ2】次に、ステップ2では、球面に加工されるべきレンズ面がレンズ面の加工誤差等により微小非球面化しているか否かについて正確なレンズ面の加工情報を得るために、ステップ1にて加工された全てのレンズのレンズ面に関して、図6に示す如きフィゾー型の干渉計を用いて各レンズのレンズ面の形状が計測される。その計測結果は、図3に示した如く、コンピュータ、計算機等の演算系7内のメモリ一部にコンソール等の入力系6を介して記憶される。なお、フィゾー型の干渉計の内部に設けられた面形状算出部と演算系7とを電気的に接続し、面形状算出部からの出力結果を演算系7のメモリ一部に入力する構成としても良い。

【0074】ここで、計測されたレンズ面の形状のデータに関する一例を表3に示す。表3に示す如く、r1～r3、r5、r6、r9～r15、r17、r19、r21～r23、r31、r34、r35、r37、r45～r47、r49～r52およびr54の29面のレンズ面は、球面レンズ面とはなっておらず、加工誤差によって非球面となっている。なお、表3に示していないr4、r7、r8、r16、r18、r20、r24、r25、r26～r30、r32、r33、r36、r38～r44、r53～r56の27面のレンズ面は表1に示す設計値どおり球面でレンズ面が加工されている。

【0075】なお、表3において、計測されたレンズ面

の非球面形状は、光軸からの高さを h とし、光軸からの高さ h における非球面上の点からレンズ頂点での接平面までの光軸に沿った距離を $X(h)$ 、近軸の曲率半径を r 、円錐定数を k 、自然数を i 、 $2i$ 次の非球面係数を C_{2i} とするとき、前述の(7)式のように表現している。

$$X(h) = A / [1 + (1 - kA/r)^{0.5}] + C_2 h^2 + C_4 h^4 + \dots + C_{2i} h^{2i}$$

r1 (レンズL₁₁の物体側面)

$k = 1$

$$\begin{aligned} C_2 &= -5.471 \times 10^{-9}, C_4 = 7.211 \times 10^{-12} \\ C_6 &= -6.987 \times 10^{-15}, C_8 = 3.581 \times 10^{-18} \\ C_{10} &= -9.940 \times 10^{-22}, C_{12} = 1.515 \times 10^{-25} \\ C_{14} &= -1.189 \times 10^{-29}, C_{16} = 3.746 \times 10^{-34} \end{aligned}$$

r2 (レンズL₁₁の像側面)

$k = 1$

$$\begin{aligned} C_2 &= 9.640 \times 10^{-9}, C_4 = -1.559 \times 10^{-11} \\ C_6 &= 7.989 \times 10^{-15}, C_8 = -1.994 \times 10^{-18} \\ C_{10} &= 2.676 \times 10^{-22}, C_{12} = -1.970 \times 10^{-26} \\ C_{14} &= 7.842 \times 10^{-31}, C_{16} = -1.486 \times 10^{-35} \end{aligned}$$

r3 (レンズL₁₂の物体側面)

$k = 1$

$$\begin{aligned} C_2 &= 2.504 \times 10^{-9}, C_4 = 1.800 \times 10^{-12} \\ C_6 &= -1.945 \times 10^{-15}, C_8 = 7.684 \times 10^{-19} \\ C_{10} &= -1.617 \times 10^{-22}, C_{12} = 1.883 \times 10^{-26} \\ C_{14} &= -1.140 \times 10^{-30}, C_{16} = 2.796 \times 10^{-35} \end{aligned}$$

r5 (レンズL₁₃の物体側面)

$k = 1$

$$\begin{aligned} C_2 &= -9.776 \times 10^{-9}, C_4 = 1.584 \times 10^{-11} \\ C_6 &= -7.836 \times 10^{-15}, C_8 = 1.971 \times 10^{-18} \\ C_{10} &= -2.706 \times 10^{-22}, C_{12} = 1.945 \times 10^{-26} \\ C_{14} &= -6.176 \times 10^{-31}, C_{16} = 3.939 \times 10^{-36} \end{aligned}$$

r6 (レンズL₁₃の像側面)

$k = 1$

$$\begin{aligned} C_2 &= -1.281 \times 10^{-8}, C_4 = 6.967 \times 10^{-12} \\ C_6 &= -1.619 \times 10^{-15}, C_8 = 2.539 \times 10^{-19} \\ C_{10} &= -4.180 \times 10^{-23}, C_{12} = 5.733 \times 10^{-27} \\ C_{14} &= -4.365 \times 10^{-31}, C_{16} = 1.315 \times 10^{-35} \end{aligned}$$

r9 (レンズL_{2F}の物体側面)

$k = 1$

$$\begin{aligned} C_2 &= -8.091 \times 10^{-9}, C_4 = 1.051 \times 10^{-11} \\ C_6 &= -1.073 \times 10^{-14}, C_8 = 5.072 \times 10^{-18} \\ C_{10} &= -1.232 \times 10^{-21}, C_{12} = 1.619 \times 10^{-25} \\ C_{14} &= -1.097 \times 10^{-29}, C_{16} = 3.005 \times 10^{-34} \end{aligned}$$

r10 (レンズL_{2F}の像側面)

$k = 1$

$$\begin{aligned} C_2 &= 1.208 \times 10^{-8}, C_4 = -3.713 \times 10^{-12} \\ C_6 &= 1.231 \times 10^{-15}, C_8 = -3.068 \times 10^{-18} \\ C_{10} &= 2.347 \times 10^{-21}, C_{12} = -7.694 \times 10^{-25} \\ C_{14} &= 1.169 \times 10^{-28}, C_{16} = -6.760 \times 10^{-33} \end{aligned}$$

但し、 $A = h^2 / r$ である。

【0076】なお、この非球面式（または(7)式）を上述の(8)式で表現した場合には、奇数次の非球面係数（ $C_1, C_3, C_5, C_7, C_9, C_{11}, C_{13}, C_{15}$ ）を全て零とした場合となる。

【0077】

【表3】

r11 (レンズL_{M1}の物体側面)

k = 1

$$C_2 = -3.296 \times 10^{-8}, C_4 = 6.279 \times 10^{-11}$$

$$C_6 = -5.572 \times 10^{-14}, C_8 = 3.563 \times 10^{-17}$$

$$C_{10} = -1.492 \times 10^{-20}, C_{12} = 3.643 \times 10^{-24}$$

$$C_{14} = -4.659 \times 10^{-28}, C_{16} = 2.397 \times 10^{-32}$$

r12 (レンズL_{M1}の像側面)

k = 1

$$C_2 = 2.002 \times 10^{-8}, C_4 = -3.252 \times 10^{-11}$$

$$C_6 = 2.300 \times 10^{-14}, C_8 = -2.545 \times 10^{-18}$$

$$C_{10} = -6.506 \times 10^{-21}, C_{12} = 3.926 \times 10^{-24}$$

$$C_{14} = -8.762 \times 10^{-28}, C_{16} = 6.968 \times 10^{-32}$$

r13 (レンズL_{M2}の物体側面)

k = 1

$$C_2 = 5.766 \times 10^{-9}, C_4 = -4.636 \times 10^{-11}$$

$$C_6 = 6.549 \times 10^{-14}, C_8 = -4.629 \times 10^{-17}$$

$$C_{14} = 5.396 \times 10^{-28}, C_{16} = -2.777 \times 10^{-32}$$

r14 (レンズL_{M2}の像側面)

k = 1

$$C_2 = 4.539 \times 10^{-8}, C_4 = -7.979 \times 10^{-11}$$

$$C_6 = 7.887 \times 10^{-14}, C_8 = -5.989 \times 10^{-17}$$

$$C_{10} = 4.596 \times 10^{-20}, C_{12} = -2.583 \times 10^{-23}$$

$$C_{14} = 7.533 \times 10^{-27}, C_{16} = -8.407 \times 10^{-31}$$

r15 (レンズL_{M3}の物体側面)

k = 1

$$C_2 = -3.853 \times 10^{-8}, C_4 = 6.880 \times 10^{-11}$$

$$C_6 = -9.409 \times 10^{-14}, C_8 = 8.629 \times 10^{-17}$$

$$C_{10} = -5.002 \times 10^{-20}, C_{12} = 1.716 \times 10^{-23}$$

$$C_{14} = -3.068 \times 10^{-27}, C_{16} = 2.139 \times 10^{-31}$$

r17 (レンズL_{M4}の物体側面)

k = 1

$$C_2 = -3.484 \times 10^{-8}, C_4 = 4.891 \times 10^{-11}$$

$$C_6 = -6.547 \times 10^{-14}, C_8 = 5.864 \times 10^{-17}$$

$$C_{10} = -3.072 \times 10^{-20}, C_{12} = 8.969 \times 10^{-24}$$

$$C_{14} = -1.308 \times 10^{-27}, C_{16} = 7.039 \times 10^{-32}$$

r19 (レンズL_{M5}の物体側面)

k = 1

$$C_2 = 9.291 \times 10^{-9}, C_4 = 1.762 \times 10^{-12}$$

$$C_6 = -5.641 \times 10^{-15}, C_8 = 3.610 \times 10^{-18}$$

$$C_{10} = -1.147 \times 10^{-21}, C_{12} = 1.958 \times 10^{-25}$$

$$C_{14} = -1.716 \times 10^{-29}, C_{16} = 6.070 \times 10^{-34}$$

r21 (レンズL_{2R}の物体側面)

k = 1

$$C_2 = -1.793 \times 10^{-9}, C_4 = 8.806 \times 10^{-12}$$

$$C_6 = -1.134 \times 10^{-14}, C_8 = 6.366 \times 10^{-18}$$

$$C_{10} = -1.936 \times 10^{-21}, C_{12} = 3.284 \times 10^{-25}$$

$$C_{14} = -2.890 \times 10^{-29}, C_{16} = 1.022 \times 10^{-33}$$

r22 (レンズL_{2R}の像側面)

k = 1

$$C_2 = 2.095 \times 10^{-8}, C_4 = -2.339 \times 10^{-11}$$

$$\begin{aligned} C_6 &= 1.406 \times 10^{-14}, C_8 = -4.552 \times 10^{-18} \\ C_{10} &= 8.283 \times 10^{-22}, C_{12} = -8.499 \times 10^{-26} \\ C_{14} &= 4.593 \times 10^{-30}, C_{16} = -1.017 \times 10^{-34} \end{aligned}$$

r23 (レンズL₃₁の物体側面)

k=1

$$\begin{aligned} C_2 &= -3.700 \times 10^{-9}, C_4 = 1.870 \times 10^{-12} \\ C_6 &= -5.376 \times 10^{-16}, C_8 = 3.559 \times 10^{-20} \\ C_{10} &= 1.000 \times 10^{-23}, C_{12} = -2.129 \times 10^{-27} \\ C_{14} &= 1.566 \times 10^{-31}, C_{16} = -4.112 \times 10^{-36} \end{aligned}$$

r31 (レンズL₄₁の物体側面)

k=1

$$\begin{aligned} C_2 &= -1.652 \times 10^{-8}, C_4 = 2.774 \times 10^{-12} \\ C_6 &= 4.818 \times 10^{-15}, C_8 = -3.252 \times 10^{-18} \\ C_{10} &= 9.372 \times 10^{-22}, C_{12} = -1.430 \times 10^{-25} \\ C_{14} &= 1.124 \times 10^{-29}, C_{16} = -3.585 \times 10^{-34} \end{aligned}$$

r34 (レンズL₄₂の像側面)

k=1

$$\begin{aligned} C_2 &= -1.756 \times 10^{-8}, C_4 = 1.631 \times 10^{-11} \\ C_6 &= -7.091 \times 10^{-15}, C_8 = 1.179 \times 10^{-19} \\ C_{10} &= 1.068 \times 10^{-21}, C_{12} = -3.875 \times 10^{-25} \\ C_{14} &= 5.632 \times 10^{-29}, C_{16} = -3.048 \times 10^{-33} \end{aligned}$$

r35 (レンズL₄₃の物体側面)

k=1

$$\begin{aligned} C_2 &= -3.427 \times 10^{-8}, C_4 = 5.336 \times 10^{-11} \\ C_6 &= -3.932 \times 10^{-14}, C_8 = 1.308 \times 10^{-17} \\ C_{10} &= -1.146 \times 10^{-21}, C_{12} = -4.070 \times 10^{-25} \\ C_{14} &= 1.117 \times 10^{-28}, C_{16} = -8.291 \times 10^{-33} \end{aligned}$$

r37 (レンズL₄₄の物体側面)

k=1

$$\begin{aligned} C_2 &= 4.750 \times 10^{-8}, C_4 = -2.692 \times 10^{-12} \\ C_6 &= -1.583 \times 10^{-14}, C_8 = 2.256 \times 10^{-17} \\ C_{10} &= -1.298 \times 10^{-20}, C_{12} = 3.758 \times 10^{-24} \\ C_{14} &= -5.379 \times 10^{-28}, C_{16} = 3.020 \times 10^{-32} \end{aligned}$$

r45 (レンズL₅₄の物体側面)

k=1

$$\begin{aligned} C_2 &= -1.581 \times 10^{-9}, C_4 = -7.300 \times 10^{-12} \\ C_6 &= 3.438 \times 10^{-15}, C_8 = -6.407 \times 10^{-19} \\ C_{10} &= 4.045 \times 10^{-23}, C_{12} = 2.557 \times 10^{-27} \\ C_{14} &= -4.391 \times 10^{-31}, C_{16} = 1.501 \times 10^{-35} \end{aligned}$$

r46 (レンズL₅₄の像側面)

k=1

$$\begin{aligned} C_2 &= -2.319 \times 10^{-8}, C_4 = 2.142 \times 10^{-11} \\ C_6 &= -9.743 \times 10^{-15}, C_8 = 2.355 \times 10^{-18} \\ C_{10} &= -3.234 \times 10^{-22}, C_{12} = 2.546 \times 10^{-27} \\ C_{14} &= -1.073 \times 10^{-30}, C_{16} = 1.877 \times 10^{-35} \end{aligned}$$

r47 (レンズL₅₅の物体側面)

k=1

$$\begin{aligned} C_2 &= 7.534 \times 10^{-9}, C_4 = -1.324 \times 10^{-12} \\ C_6 &= 1.738 \times 10^{-16}, C_8 = 1.051 \times 10^{-19} \\ C_{10} &= -4.377 \times 10^{-23}, C_{12} = 6.217 \times 10^{-27} \end{aligned}$$

$$C_{14} = -3.932 \times 10^{-31}, C_{16} = 9.384 \times 10^{-36}$$

r49 (レンズL₅₆の物体側面)

k = 1

$$C_2 = -8.499 \times 10^{-9}, C_4 = 4.471 \times 10^{-12}$$

$$C_6 = -2.412 \times 10^{-15}, C_8 = 1.080 \times 10^{-18}$$

$$C_{10} = -2.747 \times 10^{-22}, C_{12} = 3.709 \times 10^{-26}$$

$$C_{14} = -2.503 \times 10^{-30}, C_{16} = 6.654 \times 10^{-35}$$

r50 (レンズL₅₆の像側面)

k = 1

$$C_2 = -8.992 \times 10^{-11}, C_4 = 4.380 \times 10^{-12}$$

$$C_6 = -3.536 \times 10^{-15}, C_8 = 1.459 \times 10^{-18}$$

$$C_{10} = -3.388 \times 10^{-22}, C_{12} = 4.466 \times 10^{-26}$$

$$C_{14} = -3.120 \times 10^{-30}, C_{16} = 8.912 \times 10^{-35}$$

r51 (レンズL₅₇の物体側面)

k = 1

$$C_2 = -2.893 \times 10^{-8}, C_4 = -1.291 \times 10^{-14}$$

$$C_6 = 1.271 \times 10^{-14}, C_8 = -7.075 \times 10^{-18}$$

$$C_{10} = 1.863 \times 10^{-21}, C_{12} = -2.673 \times 10^{-25}$$

$$C_{14} = 2.008 \times 10^{-29}, C_{16} = -6.190 \times 10^{-34}$$

r52 (レンズL₅₇の像側面)

k = 1

$$C_2 = 1.227 \times 10^{-8}, C_4 = -1.288 \times 10^{-11}$$

$$C_6 = 1.178 \times 10^{-14}, C_8 = -5.922 \times 10^{-18}$$

$$C_{10} = 1.623 \times 10^{-21}, C_{12} = -2.449 \times 10^{-25}$$

$$C_{14} = 1.915 \times 10^{-29}, C_{16} = -6.065 \times 10^{-34}$$

r54 (レンズL₅₈の像側面)

k = 1

$$C_2 = 4.194 \times 10^{-8}, C_4 = -1.060 \times 10^{-10}$$

$$C_6 = 2.183 \times 10^{-13}, C_8 = -2.482 \times 10^{-16}$$

$$C_{10} = 1.558 \times 10^{-19}, C_{12} = -5.406 \times 10^{-23}$$

$$C_{14} = 9.678 \times 10^{-27}, C_{16} = -6.960 \times 10^{-31}$$

〔ステップ3〕次に、ステップ3では、ステップ2にてレンズ面が計測された各レンズが保持枠にそれぞれ保持されるように保持ユニットを組み立て、図4または図5に示す如く、組み立て上がった各保持ユニットを所定の順序で鏡筒に落とし込みながら投影光学系PLが組み立てられる。この組み立て工程時において、各レンズの光学面（レンズ面）の間隔に関する情報を、保持ユニットと共に鏡筒内に収納されるワッシャ（3A～3E、5A～5D）の厚さを加味しながら工具（マイクロメータ等）を用いて計測し、計測した結果をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリー部に記憶させる。

〔ステップ4〕ステップ4において、ステップ3にて組み立てられた直後の投影光学系PLの収差は、図7および図8に示すテストマスク等を用いて計測され、その時に像面弯曲が図9の曲線aに示すように発生している。

〔ステップ5〕このため、ステップ5では、投影光学系PLの調整に先立って、コンピュータ、計算機等の演算系7により、メモリー部内に記憶された2つの情報（各

レンズの面形状に関する情報（表3に示す光学データ）および組み立て工程にて得られた各レンズのレンズ面の間隔に関する情報）に基づいて、メモリー部内に予め記憶された光学基本データを修正する。そして、演算系7は、その修正された光学基本データの情報と、投影光学系PLに残存する諸収差に関する収差量に関する情報に基づいて、収差が補正し得る各レンズのレンズ面の間隔補正量を算出し、不図示のCRTモニター等の表示系8にて、各レンズのレンズ面の間隔補正量等の情報を表示する。

〔0078〕この表示された各レンズのレンズ面の間隔補正量に基づいて、図4または図5に示した検査対象となる投影光学系PL内部のワッシャ（3A～3E、5A～5D）の交換によりレンズ間の光軸方向での相対間隔を変化、あるいは光軸に対してレンズを傾斜させる等の調整手法が行われる。これにより投影光学系PLの調整がなされ、図9の各曲線aに示す如き低次の像面弯曲が除去される。この調整工程と平行して、求められた投影光学系PLの各レンズのレンズ面（光学面）の間隔の情

報をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリー部に記憶させる。

【ステップ6】ステップ6では、投影光学系PLの調整によって低次の像面弯曲が除去された後に、投影光学系PLに残存する高次の収差を測定する。

【0079】このときの測定は、ステップ2と同様にテストマスクTR1を用いて検査対象の投影光学系PLの高次の像面弯曲を検出する。本例の場合では、図9の曲線bに示す如く、高次の像面弯曲が図13に示される如く発生している。なお、本例の場合は、説明を簡単にするために、調整工程が完了した段階での投影光学系PLの各レンズの光学面（レンズ面）の間隔は表1のレンズデータに示す如く設計値どおりになっているものとする。

【0080】このステップ6の高次の収差計測工程において、図3に示す如く、計測された投影光学系PLに残存する高次の収差量に関する情報をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリー部に記憶させる。

【ステップ7】

【第1のサブステップ】高次の像面弯曲を補正すべき非球面をもとめるに先立って、まず、コンピュータ等の演算系7は、ステップ5の調整工程完了後での投影光学系PLの各レンズの光学面（レンズ面）の間隔に関する情報を用いて、ステップ5の調整工程に先立って得られた投影光学系PLの製造光学データに関する情報（ステップ2にて得られた各レンズのレンズ面の面形状に関する情報およびステップ3の組み立て工程にて得られた各レンズのレンズ面の間隔に関する情報等に基づいて、修正された投影光学系PLの組上げ時での光学データの情報）を再修正して、ステップ5の調整工程完了後における投影光学系PLの製造過程での光学データを再現する。

【0081】ここで、本例の場合は、説明を簡単にするために、調整工程が完了した段階での投影光学系PLの各レンズの光学面（レンズ面）の間隔は、表1のレンズデータに示す如く設計値どおりになっているものとする。このため、コンピュータ等の演算系7は、表1に示す投影光学系PLのデータに表3に示す非球面のデータを加味してレンズデータを更新（修正）する。

【0082】図13には、表1に示す投影光学系PLのデータに表3に示す非球面のデータを加味してレンズデータを更新（修正）した時の像面弯曲の様子を示している。図13に示す像面弯曲の曲線は、ステップ6にて実際に計測された図9の像面弯曲の曲線bと比較して、各像高にてほぼ同じ収差値を示しており、ステップ5の調整工程完了後での投影光学系PLの製造過程での光学データが再現されていることが理解できる。

【0083】次に、以上の如き再現された調整完了時の製造光学データとメモリー部内に記憶された情報として

ステップ6にて得られた投影光学系PLに残存する高次の諸収差に関する収差量に関する情報とに基づき（本例では表1及び表3に示すデータに基づき）、コンピュータ等の演算系7は光線追跡を行って、投影光学系PLに残存する高次の像面弯曲を補正できるような微小非球面を決定する。この時、本例では、第2レンズ群G₂の中間群G_{M1}内の負レンズM₂の物体側の凹形状のレンズ面（第13レンズ面）に、投影光学系PLに残存する高次の像面弯曲を補正できるような微小非球面を設計した例を示している。

【0084】ここで、第2レンズ群G₂の中間群G_{M1}内の負レンズM₂の物体側面（第13レンズ面）に設けるべき非球面のデータを表4に掲げる。なお、表4には、前述の（1）式～（5）式の対応値を併せて示してある。

【0085】

【表4】

r13（負レンズM₂の物体側面）

$k = 1$

$C_2 = 0.502 \times 10^{-7}$
 $C_4 = -0.687 \times 10^{-10}$
 $C_6 = 0.717 \times 10^{-13}$
 $C_8 = -0.605 \times 10^{-16}$
 $C_{10} = 0.308 \times 10^{-19}$
 $C_{12} = -0.870 \times 10^{-23}$
 $C_{14} = 0.128 \times 10^{-26}$
 $C_{16} = -0.767 \times 10^{-31}$

$S = 0.021 \mu\text{m}$

$S(n-1)/\lambda = 0.0430$

$C = 0.00099 (1/\text{mm})$

$d/D = 0.1802$

第2レンズ群G₂の中間群G_{M1}内の負レンズM₂の物体側の凹面（第13レンズ面）に設けるべき非球面は、図14に示す如く、光軸から最大像高（最大有効径）までの間に2つの変曲点を持つ非球面形状を有しており、レンズ面全面としては、4つの変曲点を有している。このように、非球面全面において、変曲点を4つ以上持つ構成とすることが好ましく、これにより、高次の収差をバランス良く補正することが可能となる。なお、図14は縦軸に非球面形状の変位量を示し、横軸にレンズ面の光軸からの高さを示している。

【第2のサブステップ】さて、コンピュータ等の演算系7を用いた光線追跡により求められた表4に示す如き微小非球面を投影光学系PL中の負レンズM₂の物体側の凹面（第13レンズ面）に形成するために、必要に応じて投影光学系PLの1部または全部を分解し、非球面加工を施すべき光学ユニットを取り出す。その後、光学ユニット内のレンズの取り出した後に、負レンズM₂の物体側での凹面（第13レンズ面）に対して非球面加工を図11に示した如きレンズ研磨加工機により行う。

〔第3のサブステップ〕以上の図11のレンズ研磨加工機による加工が完了すると、加工が施された負レンズM₂、蒸着工程等により反射防止膜が施された後、保持枠が取り付けられる。そして、最終的に、レンズ研磨加工機により非球面加工されたレンズを保持する光学ユニットを投影光学系PLに組み込む。

【0086】そして、組み込み完了した段階での像面弯曲を図15に示す。図15に示すように、図9の曲線b及び図13に示す如き高次の像面弯曲が除去され、優れた結像性能を持つ投影光学系PLの製造が達成されていることが理解できる。以上においては、高次の像面弯曲を補正する非球面を第2レンズ群G₂の中間群G_{M1}内の負レンズM₂の物体側面に設けた例を示したが、次に、高次の歪曲収差(ディストーション)を補正する非球面を設けた第2実施例を説明する。なお、説明を簡単にするために、第2実施例においても、前述の表1に示す基本レンズデータ及び表3に示す投影光学系を構成する各レンズの誤差非球面は、同一であるものとする。従って、表1に示すレンズデータを満たす投影光学系PLを構成する各レンズ並びに各レンズを保持する保持枠、レンズと保持枠とからなる保持ユニットを収納する鏡筒を製造する工程としてのステップ1、ステップ1にて製造されたレンズのレンズ面を形状を計測する工程としてのステップ2、および投影光学系PLを組み立てる工程としてのステップ3は同一であるため説明を省略する。

【ステップ4】以上のステップ1～ステップ3の工程を経た後、ステップ4において、ステップ3にて組み立てられた直後の投影光学系PLの収差は、図7および図8に示すテストマスク等を用いて計測され、その時に歪曲収差(ディストーション)が図10の曲線aに示すように発生している。

【ステップ5】このため、ステップ5では、投影光学系PLの調整に先立って、コンピュータ、計算機等の演算系7により、メモリー部内に記憶された2つの情報(各レンズでのレンズ面の面形状に関する情報(表3に示す光学データ)および組み立て工程にて得られた各レンズのレンズ面の間隔に関する情報)に基づいて、メモリー部内に予め記憶された光学基本データを修正する。そして、演算系7は、その修正された光学基本データの情報と、投影光学系PLに残存する諸収差に関する収差量に関する情報に基づいて、収差を補正し得る各レンズのレンズ面(光学面)の間隔補正量を算出し、不図示のCRTモニター等の表示系8にて、各レンズのレンズ面(光学面)の間隔補正量等の情報を表示する。

【0087】この表示された各レンズのレンズ面の間隔補正量に基づいて、図4または図5に示した検査対象となる投影光学系PL内部のワッシャ(3A～3E、5A～5D)の交換によりレンズ間の光軸方向での相対間隔を変化、あるいは光軸に対してレンズを傾斜させる等の調整手法が行われる。これにより投影光学系PLを調整

がなされ、図10の各曲線aに示す如き低次の歪曲収差が除去される。この調整工程と平行して、求められた投影光学系PLの各レンズの光学面(レンズ面)の間隔の情報をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリー部に記憶させる。

【ステップ6】ステップ6では、投影光学系PLの調整によって低次の歪曲収差が除去された後に、投影光学系PLに残存する高次の歪曲収差を測定する。

【0088】このときの測定は、ステップ2と同様にテストマスクTR2を用いて検査対象の投影光学系PLの高次の歪曲収差を検出する。本例の場合では、図10の曲線bに示す如く、高次の像面弯曲が図16に示される如く発生している。なお、本例の場合は、説明を簡単にするために、調整工程が完了した段階での投影光学系PLの各レンズの光学面(レンズ面)の間隔は表1のレンズデータに示す如く設計値どおりになっているものとする。

【0089】このステップ6の高次の収差計測工程において、図3に示す如く、計測された投影光学系PLに残存する高次の収差量に関する情報をコンソール等の入力系6を介してコンピュータ、計算機等の演算系7のメモリー部に記憶させる。

【ステップ7】

【第1のサブステップ】高次の歪曲収差を補正すべき非球面をもとめるに先立って、まず、コンピュータ等の演算系7は、ステップ5の調整工程完了後の投影光学系PLの各レンズの光学面(レンズ面)の間隔に関する情報を用いて、ステップ5の調整工程に先立って得られた投影光学系PLの製造光学データに関する情報(ステップ2にて得られた各レンズの面形状に関する情報およびステップ3の組み立て工程にて得られた各レンズの光学面の間隔に関する情報等に基づいて、修正された投影光学系PLの組上げ時での光学データの情報)を再修正して、ステップ5の調整工程完了後における投影光学系PLの製造過程での光学データを再現する。

【0090】ここで、第2実施例の場合も、前述の第1実施例と同様に、説明を簡単にするために、調整工程が完了した段階での投影光学系PLの各レンズの光学面(レンズ面)の間隔は、表1のレンズデータに示す如く設計値どおりになっているものとする。このため、コンピュータ等の演算系7は、表1に示す投影光学系PLのデータに表3に示す非球面のデータを加味してレンズデータを更新(修正)する。

【0091】図16には、表1に示す投影光学系PLのデータに表3に示す非球面のデータを加味してレンズデータを更新(修正)した時の歪曲収差の様子を示している。図16に示す歪曲収差の曲線は、ステップ6にて実際に計測された図9の歪曲収差の曲線bと比較して、各像高にてほぼ同じ収差値を示しており、ステップ5の調整工程完了後の投影光学系PLの製造過程での光学データ

ータが再現されている理解できる。

【0092】次に、以上の如き再現された調整完了時の製造光学データとメモリ一部内に記憶された情報としてステップ6にて得られた投影光学系PLに残存する高次の諸収差に関する収差量に関する情報に基づき(本例では表1及び表3に示すデータに基づき)、コンピュータ等の演算系7は光線追跡を行って、投影光学系PLに残存する高次の歪曲収差を補正できるような微小非球面を決定する。この時、本例では、第1レンズ群G₁の正レンズL₁₁の物体側の凸形状のレンズ面(第1レンズ面)に、投影光学系PLに残存する高次の歪曲収差を補正できるような微小非球面を設計した例を示している。

【0093】ここで、第1レンズ群G₁の正レンズL₁₁の物体側のレンズ面(第1レンズ面)に設けるべき非球面のデータを表5に掲げる。なお、表5には、前述の(1)式～(5)式の対応値を併せて示してある。

【0094】

【表5】

r1(正レンズL₁₁の物体側面)

k = 1

C₂ = 0.502 × 10⁻⁷

C₄ = -0.392 × 10⁻¹⁰

C₆ = 0.162 × 10⁻¹³

C₈ = -0.471 × 10⁻¹⁷

C₁₀ = 0.921 × 10⁻²¹

C₁₂ = -0.109 × 10⁻²⁴

C₁₄ = 0.696 × 10⁻²⁹

C₁₆ = -0.183 × 10⁻³³

S = 0.024 μm

S(n-1)/λ = 0.049

C = 0.00138 (1/mm)

d/D = 0

第1レンズ群G₁の正レンズL₁₁の物体側の凸形状のレンズ面(第1レンズ面)に設けるべき非球面は、図17に示す如く、光軸から最大像高(最大有効径)までの間に2つの変曲点を持つ非球面形状を有しており、レンズ面全面としては、4つの変曲点を有している。このように、非球面全面において、変曲点を4つ以上持つ構成とすることが好ましく、これにより、高次の収差をバランス良く補正することが可能となる。なお、図17は縦軸に非球面形状の変位量を示し、横軸にレンズ面の光軸からの高さを示している。

【第2のサブステップ】さて、コンピュータ等の演算系7を用いた光線追跡により求められた表4に示す如き微小非球面を投影光学系PL中の第1レンズ群G₁の正レンズL₁₁の物体側面に形成するために、必要に応じて投影光学系PLの1部または全部を分解し、非球面加工を施すべき光学ユニットを取り出す。その後、光学ユニット内のレンズの取り出した後に、正レンズL₁₁の物体側でのレンズ面(第1レンズ面)に対して非球面加工を図

11に示した如きレンズ研磨加工機により行う。

【第3のサブステップ】以上の図11のレンズ研磨加工機による加工が完了すると、加工が施された正レンズL₁₁は蒸着工程等により反射防止膜が施された後、保持枠が取り付けられる。そして、最終的に、レンズ研磨加工機により非球面加工されたレンズを保持する光学ユニットを投影光学系PLに組み込む。

【0095】そして、組み込み完了した段階での歪曲収差を図18に示す。図18に示すように、図10の曲線b及び図16に示す如き高次の歪曲収差が除去され、優れた結像性能を持つ投影光学系PLの製造が達成されていることが理解できる。以上の各実施例では、像面弯曲と歪曲収差をそれぞれ独立に補正する非球面を示したが、投影光学系に残存する各収差を同時に補正する非球面を少なくとも1面以上形成しても良い。また、本発明による非球面は、像面弯曲、歪曲収差のみならずコマ収差、球面収差、非点収差等の収差やテレセントリック性などの結像特性などを補正することも可能である。さらには、これらの複数の収差等を同時に補正することも可能である。

【0096】さらに、以上の各実施例では、屈折力を持つレンズのレンズ面に非球面を形成した例を示したが、本発明では、平凸レンズの平面側(屈折力が零となる面)または平凹レンズの平面側(屈折力が零となる面)において、投影光学系中に残存する高次の収差を補正する非球面を形成しても良い。さらには、本発明では、投影光学系を反射屈折型の光学系で構成した場合、あるいは投影光学系を反射光学系で構成した場合における少なくとも1つの反射面に、投影光学系中に残存する高次の収差を補正する非球面を形成しても良い。

【0097】また、投影光学系とマスクとの間又は投影光学系と感光性基板(ウエハ)との間において、屈折力が零となる光透過性の平行平面板を挿脱可能に構成し、その平行平面板の表面において、投影光学系中に残存する高次の収差を補正する非球面を形成しても良い。この場合、以上に述べたステップ1からステップ8まで同じ工程を経ることになるが、投影光学系からの平行平面板の取り出し並びに投影光学系への平行平面板の取り付けが非常に簡単である。その結果、平行平面板を非球面加工する場合には、第2のサブステップにて非球面加工を施すための光学素子を取り出すために必要に応じて投影光学系PLの1部または全部を分解する作業および第3のサブステップにおいて非球面加工、反射防止膜のコートが施された光学素子を取りつけるために投影光学系PLを再度組み立て、調整する作業を不要とすることができる作業効率を向上させることができる。

【0098】なお、投影光学系に残存する収差を補正する本発明による非球面は、収差の回転対称な成分のみならず回転非対称な収差成分を除去できることは言うまでもない。このため、本発明による非球面は、光軸に対し

て回転非対称な形状としても良いことは明らかである。また、以上の各実施例では、マスクパターンを感光性基板に縮小投影する投影光学系に残存する高次の収差を補正する非球面を設けた例を示したが、これに限らず、マスクパターンを感光性基板に等倍、または拡大で投影する投影光学系に残存する高次の収差を補正する非球面を設けても良い。

【0099】以上に示した各実施例では、投影光学系を構成する光学部品の加工精度が緩くても、組み上げた結果物としての投影光学系では高次の収差成分が除去されて高い光学性能を有することになるため、光学部品自体の不良率を低下させ、効率よく投影光学系を製造できる利点がある。また、光学部品の加工精度が今までと同程度であれば、今まで以上に高い光学性能を達成できる利点がある。

【0100】

【発明の効果】以上の如く、本発明によれば、投影光学系を構成する光学部品の不良や、投影光学系自身の不良を招くことなく、高次の収差成分が除去された高い光学性能を持つ投影光学系の効率の良い製造を可能とし得る。このため、本発明では、高次の収差成分が除去し得る投影光学系の製造方法、より微細なマスクパターンを感光性基板に良好に投影露光し得る投影露光装置、さらにはより高い集積度を持つ半導体素子を始めとした各種の素子の製造方法が実現できる。

【図面の簡単な説明】

【図1】図1は本発明による投影露光装置の概略構成する説明するための図である。

【図2】図2は本発明による投影光学系の製造過程を説明するための図である。

【図3】図3は本発明による投影光学系の製造過程の光学データを再現するための過程を示す図である。

【図4】図1に示した投影光学系の保持構造の様子を示す図である。

【図5】図4に示した投影光学系の保持構造とは別の構造を示す図である。

【図6】投影光学系を構成する光学素子の光学面の形状を計測するフィズー型干渉計の構成を示す図である。

【図7】投影光学系に残存する像面弯曲を計測するためのテストマスクの様子を示す図である。

【図8】投影光学系に残存する歪曲収差を計測するためのテストマスクの様子を示す図である。

【図9】投影光学系に残存する像面弯曲の様子を示す図である。

【図10】投影光学系に残存する歪曲収差の様子を示す図である。

【図11】投影光学系に残存する高次の諸収差を補正する非球面を光学面に形成する非球面加工機の構成を示す図である。

【図12】本発明の実施例にかかる投影光学系のレンズ構成図である。

【図13】図12に示した投影光学系に高次の像面弯曲が残存している様子を示す図である。

【図14】図13に示した高次の像面弯曲を補正するための非球面形状の様子を示す図である。

【図15】図14に示した非球面形状によって高次の像面弯曲が補正されている様子を示す図である。

【図16】図12に示した投影光学系に高次の歪曲収差が残存している様子を示す図である。

【図17】図16に示した高次の歪曲収差を補正するための非球面形状の様子を示す図である。

【図18】図17に示した非球面形状によって高次の歪曲収差が補正されている様子を示す図である。

【図19】走査型投影露光装置の概略的な構成を示す図である。

【符号の説明】

R …… マスク

W …… ウエハ

P L …… 投影光学系

1、4 A～4 E、…… 鏡筒

2 A～2 E …… 保持枠

3 A～3 E、5 A～5 D …… ワッシャ

L₁～L₅ …… レンズ

G₁ …… 第1レンズ

G₂ …… 第2レンズ

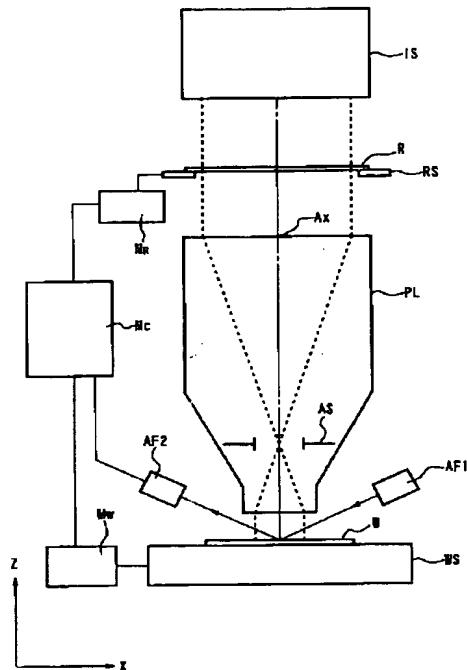
G₃ …… 第3レンズ

G₄ …… 第4レンズ

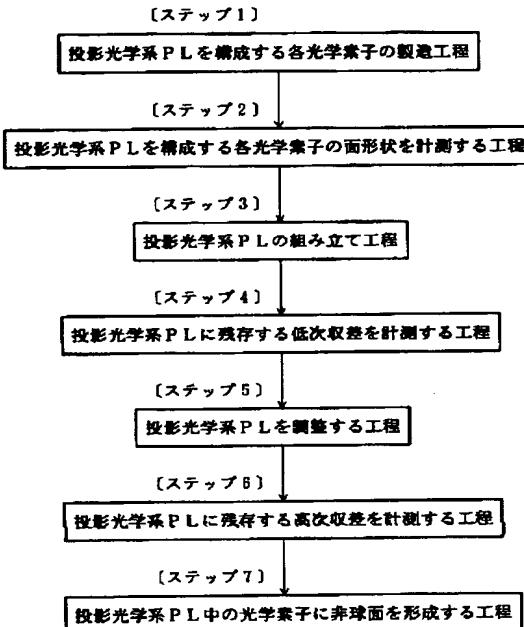
G₅ …… 第5レンズ

G₆ …… 第6レンズ

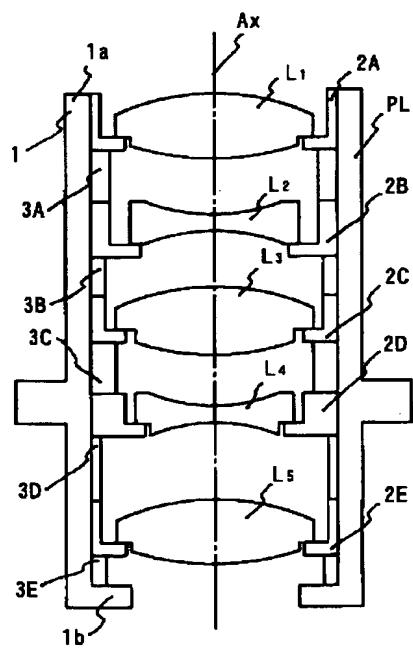
【図1】



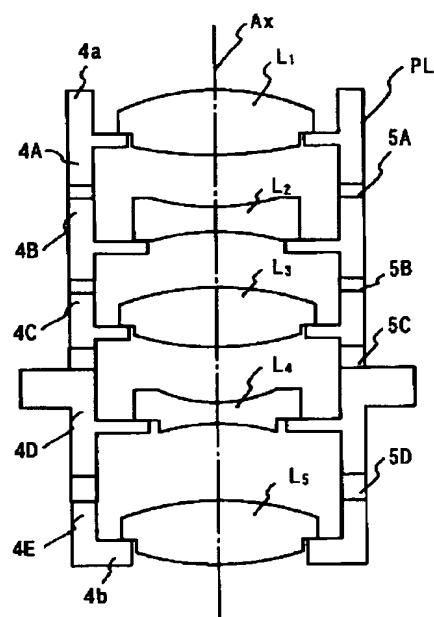
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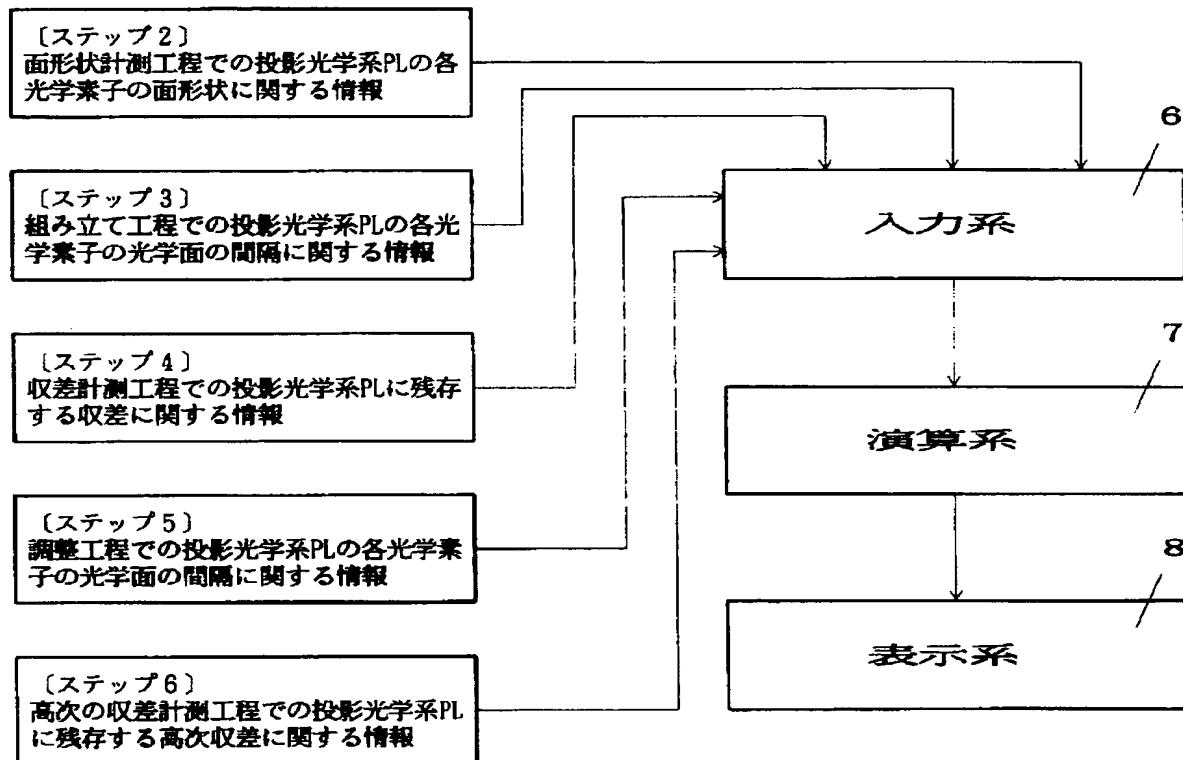
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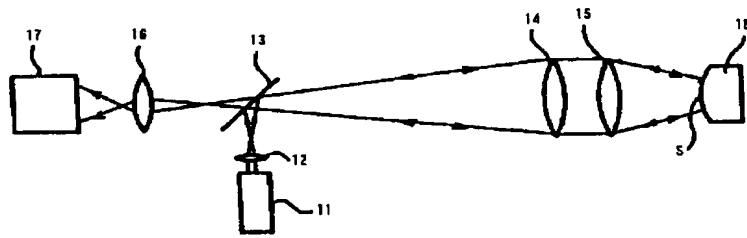
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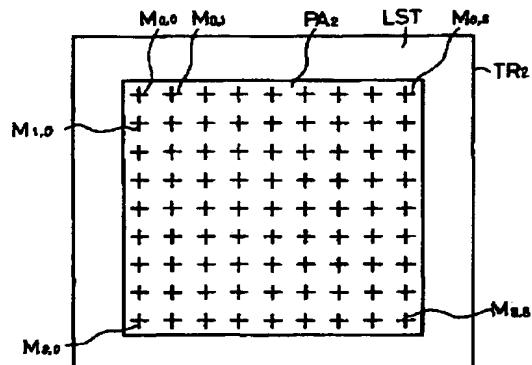
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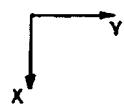
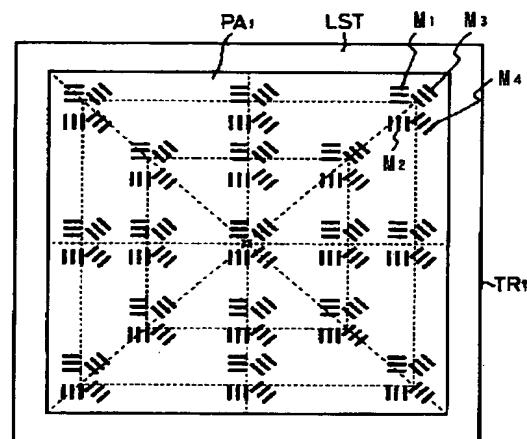
【図6】



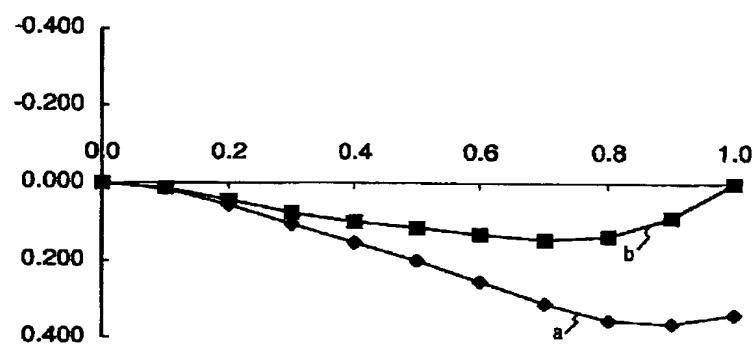
【図7】



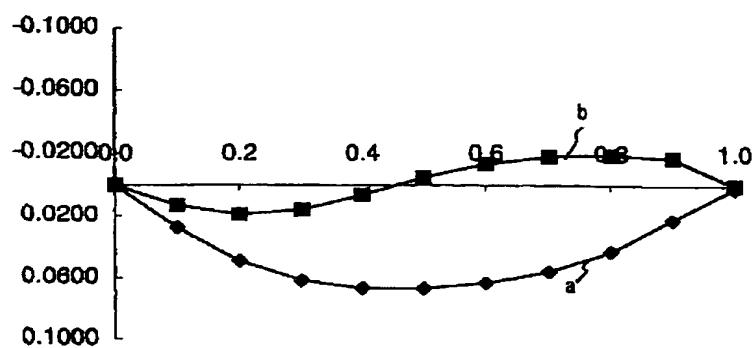
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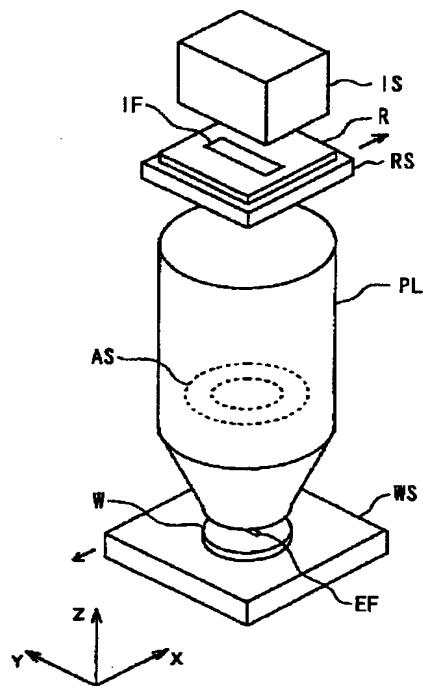
【図9】



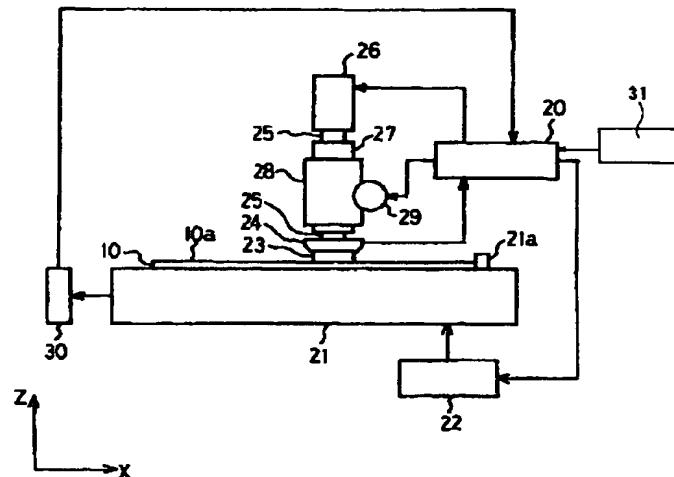
【図10】



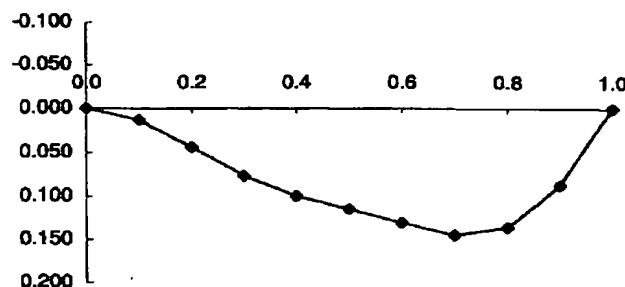
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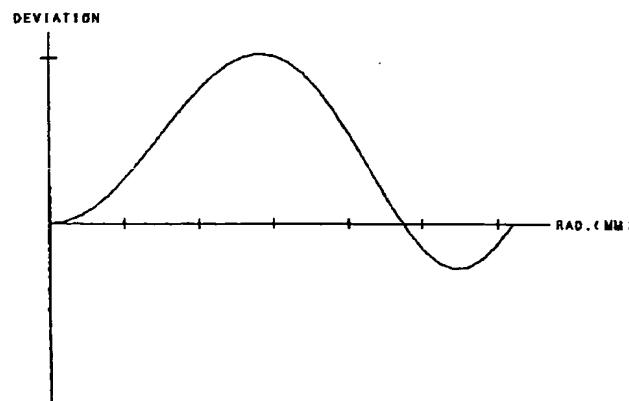
【図11】



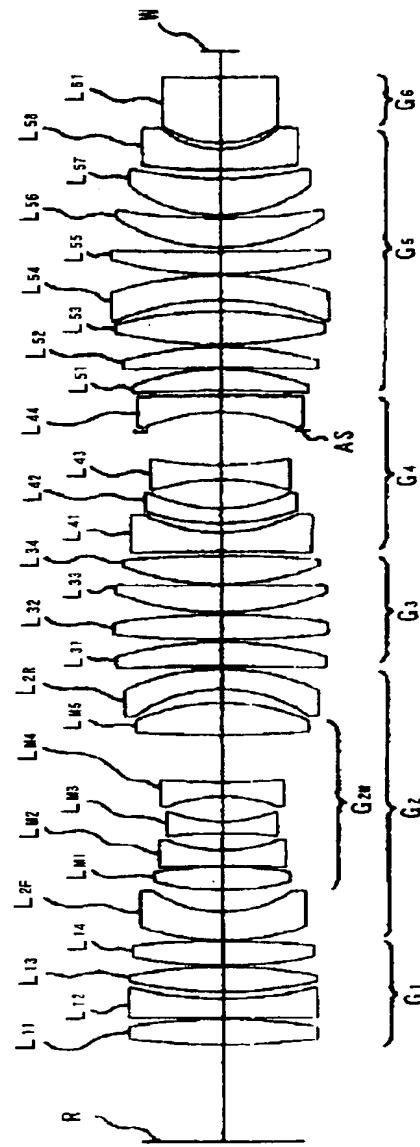
【图13】



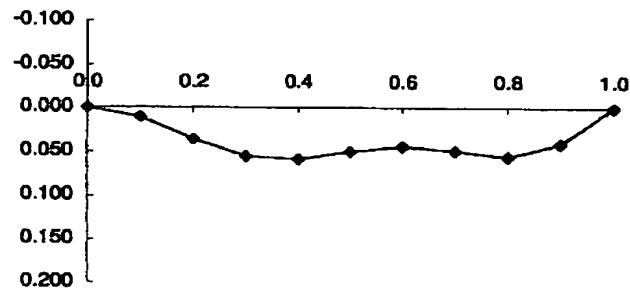
【図14】



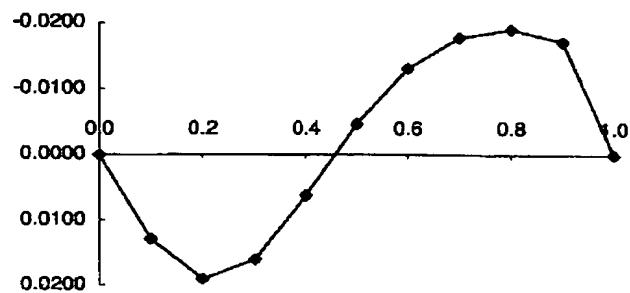
【図12】



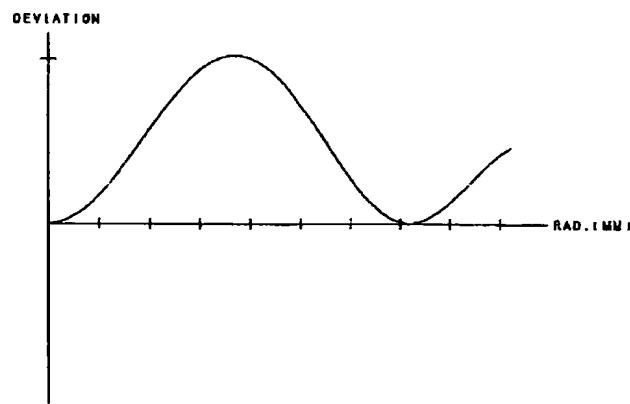
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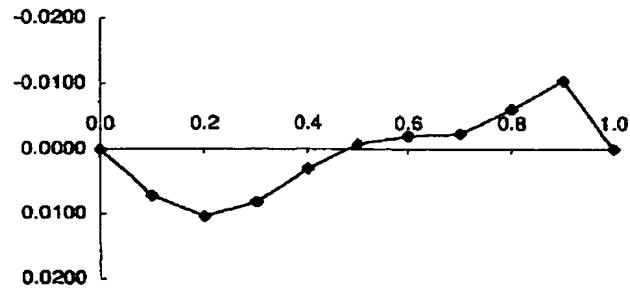
【図16】



【図17】



【図 18】



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